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DRAFT

COMPARATIVE EVALUATION OF EFFECTS OF OZONATED AND CHLORINATED THERMAL DISCHARGES ON ESTUARINE AND FRESHWATER ORGANISMS

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Comparative Evaluation of Effects of Ozonated and Chlorinated Thermal Discharges on Estuarine and Freshwater Organisms

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Final Report

Prepared by

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CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

As a part of a program at PSE&G designed to examine the feasibility of ozonation as an alternative to chlorination for control of biofouling in once-through cooling systems, the biological effects of ozonated and chlorinated thermal discharges were evaluated with estuarine and freshwater organisms. Results of tests evaluating lethal effects at salinities between 0.5-2.5 ppt with mummichog and white perch indicated that the biological effects of ozone were less severe than those of chlorine. Conversely, results of toxicity tests with alewife, spottail shiner, rainbow trout and white perch in freshwater indicated that the biological effects of chlorine were less severe than those of ozone. In general, the relative effects of ozone and chlorine in behavioral and physiographic studies were consistent with those observed in toxicity studies. Initial "cough" response and avoidance concentrations of mummichog and white perch in estuarine waters were lower when exposed to chlorine than when exposed to ozone. In freshwater, blueback herring, alewife, rainbow trout, spottail shiner, banded killifish, and white perch avoided lower concentrations of ozone than chlorine. Although rainbow trout and banded killifish exhibited lower initial "cough" response concentrations when exposed to ozone than when exposed to chlorine in freshwater, spottail shiner exhibited about the same sensitivity to chlorine and ozone. However, white perch in freshwater exhibited a lower initial "cough" response concentration when exposed to chlorine than when exposed to ozone. Differences in the oxidative by-products formed by ozone and chlorine in estuarine and fresh waters could account for the site-specific biological effects.

Section 1

INTRODUCTION

Steam-electric power plants require vast quantities of cooling water to condense the steam used to drive their turbines. The electric utility industry is responsible for approximately one-quarter of all water withdrawals in the U.S. These cooling waters contain a variety of biofouling organisms that are capable of attaching to the walls of intake structures and condenser tubes. Accumulation of deposits can promote corrosion resulting in leakage of cooling water and contamination of boiler feedwater. The attached biofouling material also acts as an insulator on the heat exchanger surfaces, directly affecting condenser efficiency and back pressure. This reduction in heat transfer efficiency decreases generating capacity of the system and necessitates an increase in fuel consumption to maintain production levels. In extreme cases, biofouling can continue to a point where cooling water flow becomes restricted and costly unit shutdowns are required for cleaning.

A majority of the industry has traditionally used chlorine to control biofouling. During 1975, the most recent year for which figures are available, 559 of the 791 generating stations surveyed in the U.S. added a total of 27,339 tons of chlorine to their cooling waters (1).

The effectiveness of chlorine in destroying biofouling organisms is also responsible for its adverse effects in the natural ecosystem. Chlorinated discharges have been found to be responsible for fish kills (2), destruction of phytoplankton (3) and other deleterious sublethal effects. Chlorine is also capable of producing halogenated organic by-products, whose effects as yet, are unknown (4,5).

As a possible alternative to chlorination for controlling biofouling in utility plant condenser systems, Public Service Electric and Gas Company has been evaluating the effectiveness, and technical and economic feasibility of ozonation (6). A pilot-scale condenser system was used at PSE&G's Bergen Generating Station to simulate plant condenser operations. The facility provides a reliable means for monitoring biofouling growth by measurement of the heat transfer coefficient across the condenser tubes and/or the waterside pressure drop. Three model condensers operated in parallel facilitate the simultaneous evaluation of chlorine and ozone compared to an untreated control.

In conjunction with this study the biological effects of the ozonated and chlorinated thermal discharges have been evaluated. This evaluation, sponsored jointly by the U.S. Department of Energy and PSE&G, compares the effects of ozonated and chlorinated thermal discharges on estuarine and freshwater organisms. This report covers the biological evaluations conducted at PSE&G's Bergen Generating Station (February-June 1979) utilizing the pilot-scale condenser system; and at PSE&G's Mercer Generating Station (November 1979-July 1980) where the pilot-scale condenser system was replaced by a chlorinator, ozonator and heat exchanger.

OBJECTIVES

The objectives of the biological study were to experimentally evaluate the lethal and sublethal effects of ozonated and chlorinated thermal effluents on estuarine and freshwater organisms. Lethal effects are those that result in direct mortality. Sublethal effects are numerous but generally can be demonstrated by behavioral avoidance or physiological and pathological consequences.

The experimental approach taken in this study was based on the hypothesis that motile organisms, such as fishes, will avoid lethal conditions. Avoidance concentrations would therefore be lower than those which resulted in mortality. However, if organisms remained in the area of the discharge they could experience some detrimental physiological or pathological effects. It is expected that such concentrations would be detected by the organism but would be lower than those concentrations which elicited avoidance.

The biological evaluation program incorporated three types of experimental tests: acute (96-hr) toxicity studies; behavioral (avoidance) response studies; and physiographic ("cough" response) studies. In addition, specimens used in testing were examined for physical damage resulting from exposure to chlorine or ozone.

The objective of the acute (96-hr) toxicity study was to determine the respective lethal levels (LC_{50}) for intermittent exposure of chlorinated and ozonated waters. The objective of the behavioral (avoidance) response study was to determine what (if any) concentrations of ozone and of chlorine would be avoided. The objective of the physiographic ("cough" response) study was to determine what concentrations of ozone and chlorine were physiologically detected.

Section 2

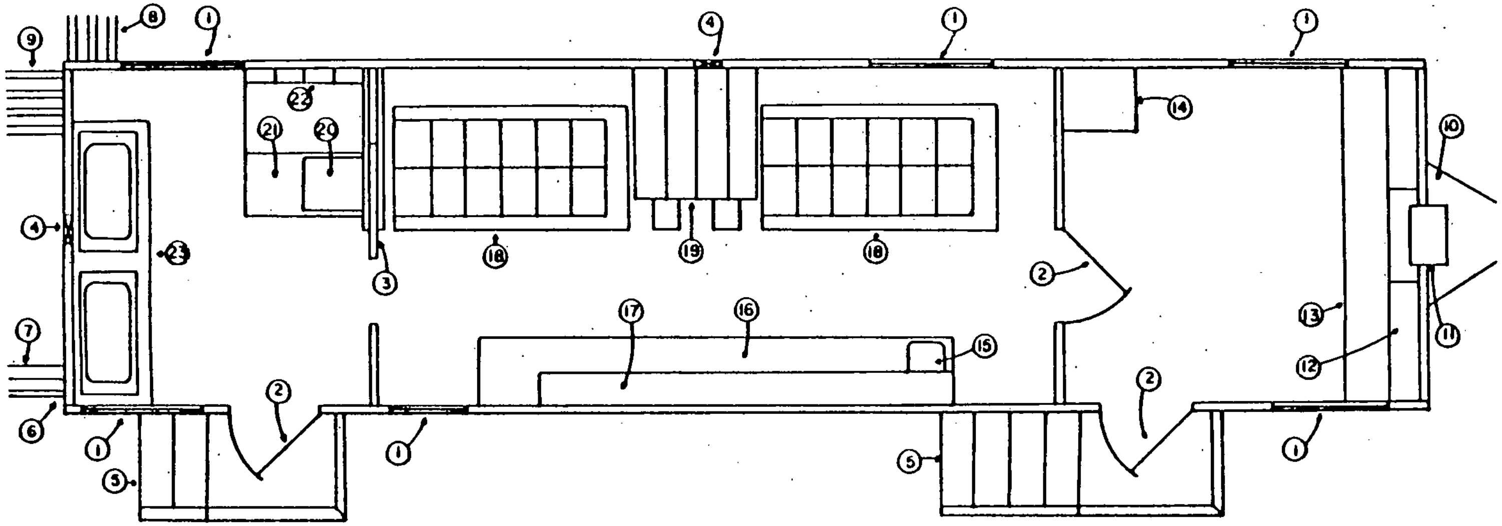
EXPERIMENTAL METHODS

LABORATORY DESCRIPTION

A 12 ft x 46 ft mobile trailer was used as a laboratory for the biological evaluation (see Figure 1). The laboratory was divided into three rooms; an office was located in the front room, a holding facility and physiographic system were located in the back room, and the toxicity and avoidance systems were located in the middle room. Treated and untreated water were supplied to the experimental systems through separate pipes for each water condition (untreated, chlorinated, and ozonated).

While at the Bergen Generating Station (see Figures 2 and 3), the Biological Evaluation Laboratory was located adjacent to Overpeck Creek, a tributary of the Hackensack River, and to PSE&G's Water Quality Laboratory which was equipped with the pilot-scale condenser system. Discharge water from each of the three test condensers (untreated, chlorinated, and ozonated) was piped separately to the delivery system in the Biological Evaluation Laboratory. However, most of the biological tests were conducted independently of the dosing schedule for the condenser system because the levels of chlorine and ozone employed in that study were too low for biological testing purposes.

For testing at the Mercer Generating Station (see Figures 2 and 4) the Biological Evaluation Laboratory was located adjacent to the Delaware River from which ambient untreated water was withdrawn. A water intake system and biocide dosing system independent of PSE&G's Water Quality Laboratory were incorporated into the delivery system at Mercer. Ozone was produced from oxygen by a water-cooled Welsbach Model T-816 laboratory ozonator. Chlorination was accomplished by injection of chlorine gas with a Capital Controls Co. advanced gas chlorinator Model 201. A heat exchanger designed to produce a 2-3 C temperature rise was used to simulate the effects of the thermal effluent from the generating station.



1) Window
2) Door
3) Sliding Door
4) Fan
5) Stairs
6) City Water Inlet
7) Sink Drain
8) River Water Inlet
9) Tank Drains
10) Trailer Hitch
11) Air Conditioner
12) Shelves
13) Desk
14) Refrigerator
15) Sink
16) Lab Bench
17) Cabinets (above & below bench)
18) Toxicity Tanks
19) Avoidance Tanks
20) Physiograph
21) Table
22) Test Chambers
23) Holding Facility

Figure 1. Biological evaluation laboratory floor plan.

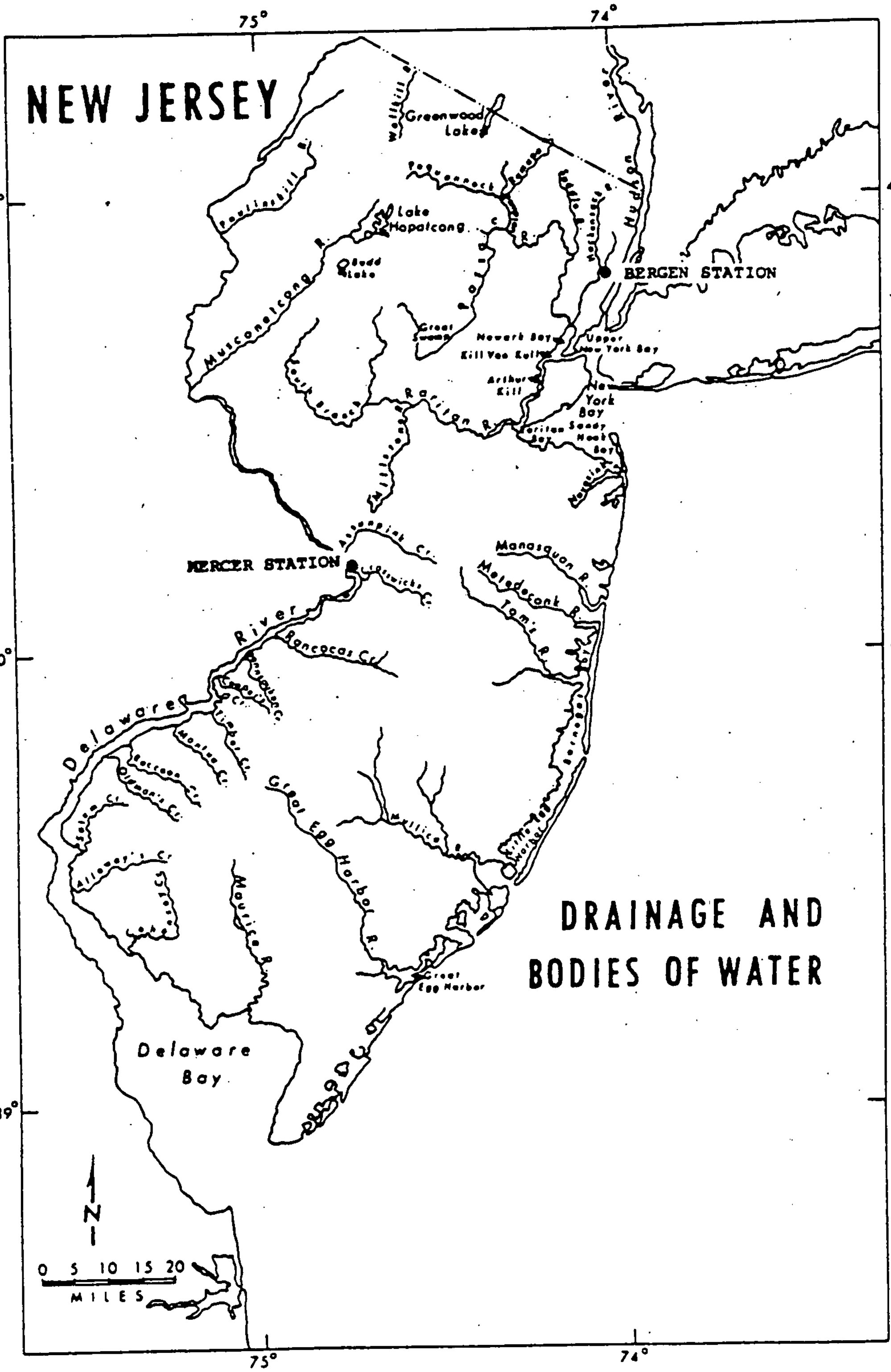


Figure 2. Locations of Bergen and Mercer Generating Stations in New Jersey.

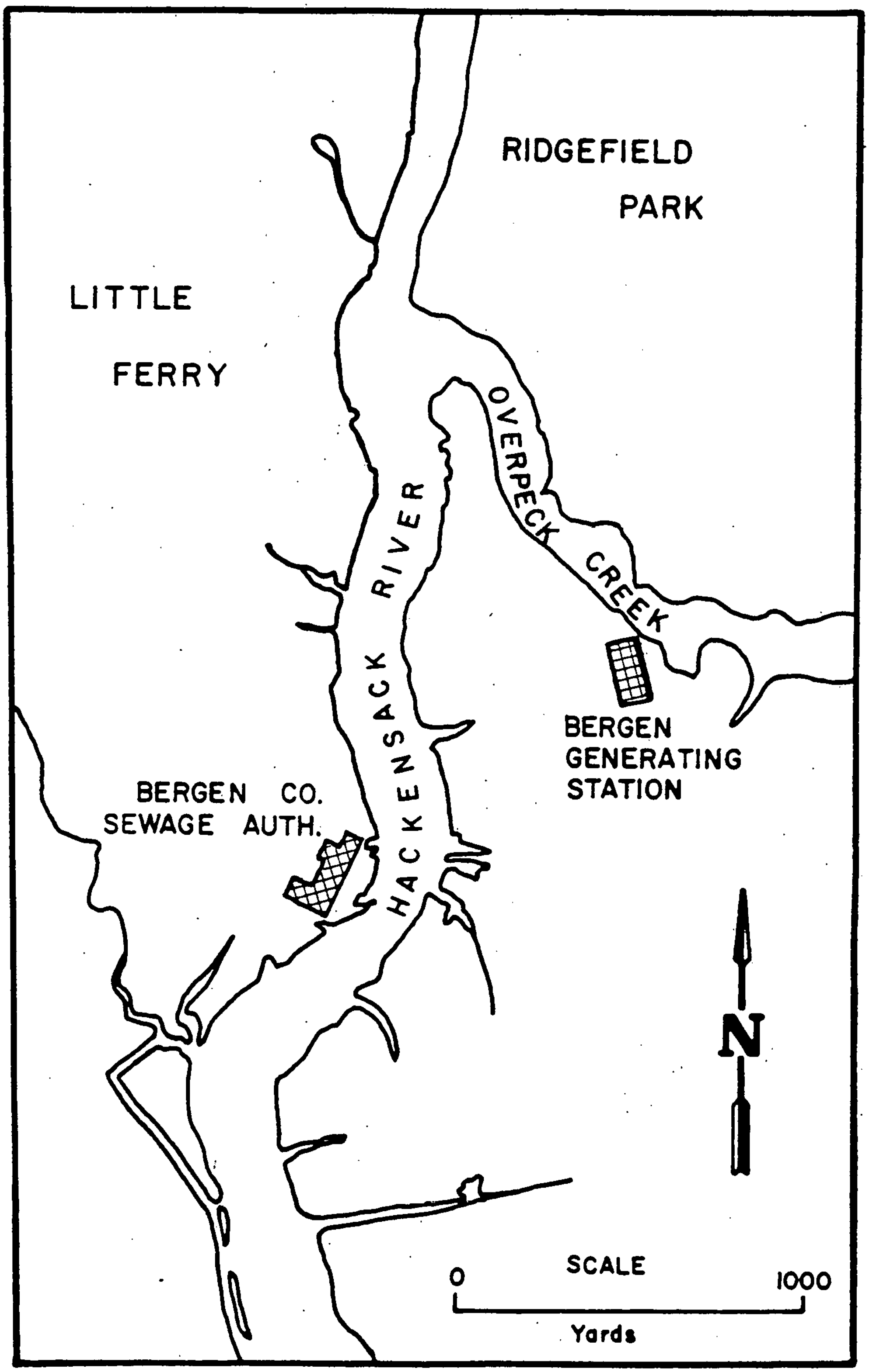


Figure 3. Detailed location of Bergen Generating Station.

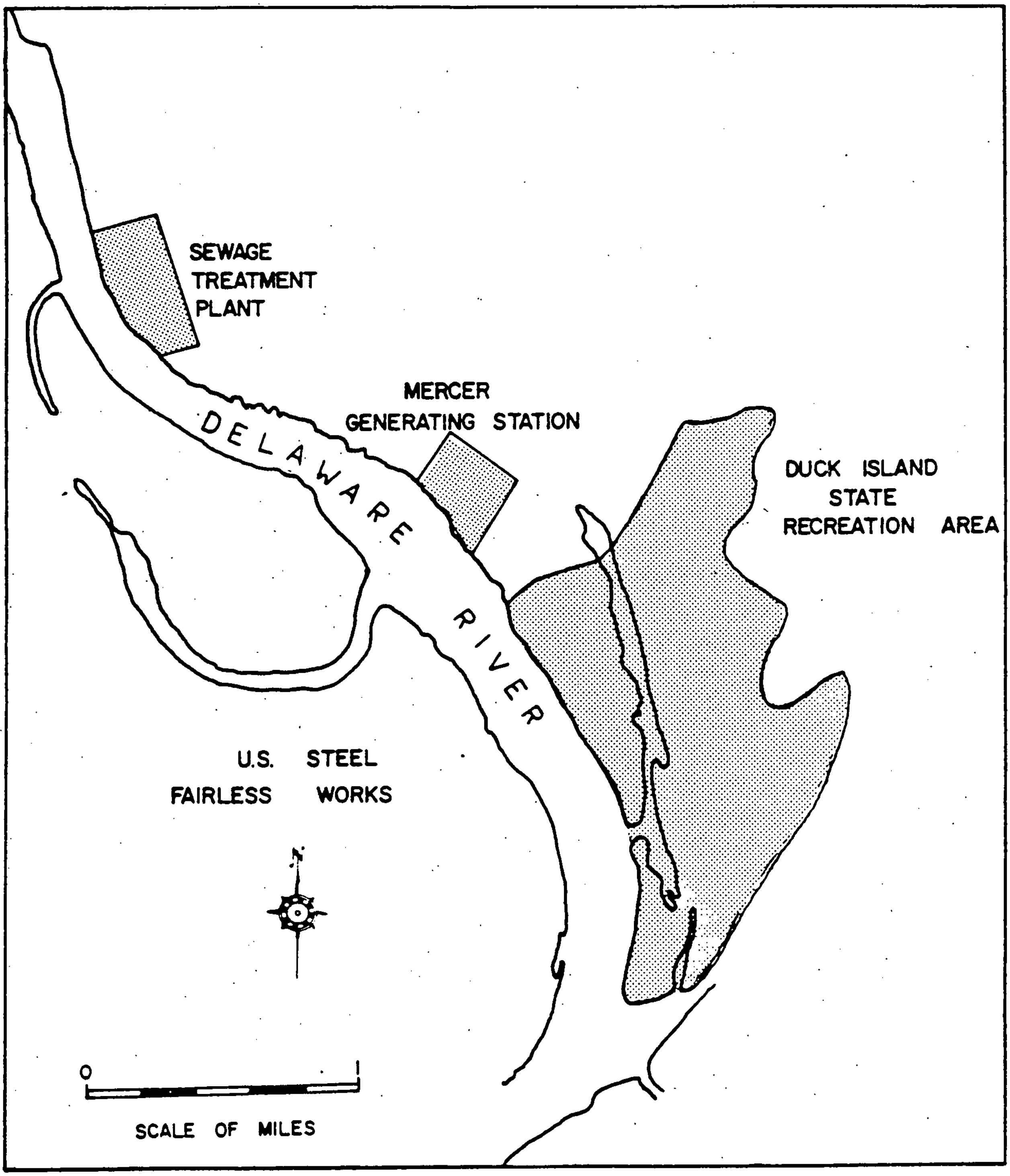


Figure 4. Detailed location of Mercer Generating Station.

The holding facility was a flowing-water, closed-cycle system consisting of three 50-gallon (190 liter) oval holding tanks and an 88-gallon (333 liter) delivery tank. The delivery tank supplied water to the holding tanks and was equipped with heaters and a refrigeration unit for temperature control. Water in the delivery tank was sterilized with an ultraviolet sterilizer, aerated, and filtered. Water was changed or replenished whenever necessary. The holding facility was maintained at ambient light levels under natural photoperiod. Additional holding facilities consisting of two 50-gallon (190 liter) tanks and one 250-gallon (946 liter) tank were used at Mercer. At Bergen, because of low dissolved oxygen and the poor quality of Overpeck Creek water, test organisms were maintained in dechlorinated city water and adjusted with "Forty Fathoms marine mix" to salinities between 0.1 and 10 ppt. At Mercer test organisms were maintained in filtered Delaware River water. To prevent fungus and disease, when acclimation temperatures were above 18 C at Mercer, the river water was ozonated and allowed to deozonate for several hours and adjusted to salinities between 1 and 3 ppt before it was introduced to the holding facility.

TESTING PROCEDURES

Toxicity Studies

The toxicity system consisted of two 4 ft x 8 ft tanks, each containing twelve 10-gallon (39 liter) testing chambers surrounded by a water bath. One set of tanks was used to test chlorine and the other to test ozone. Each tank was constructed of 3/4 inch exterior plywood and coated with inert epoxy resin. Nylon mesh baskets were suspended in each testing chamber to test invertebrates and small fish. Test concentrations were delivered to the test chambers below the surface of the water by mixing untreated water with treated water in the appropriate proportions from the delivery system. Chlorine and ozone tests were conducted concurrently. Five test concentrations and one control were usually used for each biocide.

Initial toxicity testing at Bergen and all tests at Mercer were conducted using flow-through exposure to chlorinated or ozonated water for two hours per day with a continuous flow of untreated water between exposure periods. Organisms were exposed for a duration of two hours once every 24 hours for 2 to 4 consecutive days at several concentrations of chlorinated or ozonated water. Aeration was not provided. Controls were maintained in untreated water. However, because of poor water quality and low levels of dissolved oxygen at Bergen, the results using this procedure were unsatisfactory. Modifications in the testing procedure were then implemented to improve survival.

The test condition between exposure periods at Bergen was modified from the continuous flow-through to a static aerated condition. Test chambers were filled with untreated water and aerated to acceptable levels of dissolved oxygen. When this had been accomplished organisms were introduced and test concentrations were set. During the 2 hour exposure period the test was conducted in a continuous flow-through mode and aeration was supplied to the untreated control and chlorine chambers (supplemental aeration of the ozonated water was not necessary). At the conclusion of the exposure period all test chambers were returned to the aerated static condition.

At Bergen, during February and part of March a flow rate of 0.5 gallons per minute (1.9 liters per minute) was used in each test chamber. However, clogging problems necessitated changing this to 1 gallon per minute (3.8 liters per minute) in the remaining tests. No toxicity tests were conducted after March at Bergen due to the low concentrations of ozone and chlorine employed in the pilot-scale condenser study.

At Mercer, a flow rate of 0.5 gallons per minute (1.9 liters per minute) and a tank capacity of 10 gallons (39 liters) were used except for ozone tests conducted in June and July. Due to an inability to maintain sufficient levels of ozone in solution under these conditions during June and July, ozone tests were conducted with a flow rate of 1 gallon per minute (3.8 liters per minute) and a tank capacity of 5 gallons (18.9 liters).

Daily average test concentrations for each of the ozone levels were determined by averaging five measurements taken during each 2 hr exposure period. The daily average chlorine concentrations were determined by averaging four to eight measurements. The final test concentrations were determined by averaging the daily averages.

Observations were made periodically during each test. Time of loss of equilibrium and death (defined as cessation of opercular activity and lack of response to prodding with a probe) were recorded for periods up to 96 hours. Dead organisms were removed when observed, measured, and in some cases, weighed and preserved by freezing. At the end of a test the remaining (live) organisms were measured, and in some cases, weighed, examined and preserved. Gill tissues of selected specimens which survived and of most specimens which died were examined for damage with a dissection microscope.

Water temperature, dissolved oxygen, pH, and salinity were measured before and during each exposure period.

Avoidance Studies

Behavioral responses of organisms to chlorinated and ozonated waters were evaluated in an avoidance system consisting of two modified Shelford-Allee avoidance apparatuses (7). Each apparatus was 2 ft x 6 ft, subdivided into 1 ft x 6 ft sub-troughs, and made of 3/4 inch exterior plywood coated with inert epoxy resin. The system was enclosed in black plastic to permit movement around it without disturbing the test organisms and for light control. A Duro-Test "Vita-Lite", which has a similar spectral distribution to sunlight, was used for lighting. Light level, measured with a Weston Model 614 light meter having a precision to two foot-candles, was maintained at 430 lux. Each apparatus had a dose box which was divided into two compartments. One side received untreated water from the delivery system. The other side received untreated and treated water from the delivery system to produce a desired concentration. Water from each side of the dose box flowed to diagonally opposite ends of the sub-troughs and then drained in the center. Due to a sharp gradient at the center drains each apparatus was thus "divided" into quadrants. Concentrations in the dose box were produced by adjusting flowmeters and the flow into each sub-trough was further regulated by flowmeters. Organisms were exposed to successively increased concentrations of ozone or chlorine in a "step-gradient" fashion and their responses observed.

At the beginning of a test equal numbers of test organisms were placed into each sub-trough of the respective apparatus. After a five minute orientation period the amount of time spent in each quadrant (formed by the center drains) was determined for a duration of five minutes and a frequency distribution of organisms-times was formed. A test continued until an avoidance response with a 2:1 ratio of time in control to time in treated water, or death was exhibited. Concentrations of the biocides were determined throughout each test. Water temperature, dissolved oxygen, pH, and salinity were measured before and at the end of each test. At the end of each test, organisms were measured and in some cases, weighed and examined. Because of the size limitations of the testing facility fishes exceeding 200 mm total length were not utilized.

At Mercer, observations were made via closed-circuit television and, when fish were very active, recorded on video-tape for subsequent analysis.

Physiographic ("Cough" Response) Studies

The physiographic system consisted of four testing chambers and a four channel Narco Desk Model DMP-4B physiograph. The test chambers were based on a design given by Spoor, et al (8) with some modifications. Each chamber was made of 1/4 inch Plexiglas and divided into three compartments: (1) intake, (2) middle compartment which housed the fish, and (3) drain. Plexiglas dividers were placed in the middle compartment which forced the fish to assume a position perpendicular to the ends of the chamber. Stainless steel wire electrodes were placed at each end of the middle compartment. The electrodes were then connected to the physiograph which recorded respiratory responses of the test organisms.

Two chambers received a continuous flow of untreated water, one chamber received chlorinated water and the other chamber received ozonated water. Usually, at least two chambers were used during a test; one with untreated water and one with a biocide. All water was taken from the avoidance system dose boxes. Each chamber was placed in a three-sided compartment with the fourth side covered with black plastic. Initially, observations were made via small slits in the black plastic. Later, one-way mirrors were added to the system to facilitate observations. Lighting was provided by a Duro-Test "Vita-Lite" connected to an electric timer to simulate natural photoperiod. Light level during daylight was maintained at 430 lux. Because of the size limitations of the chambers and the sensitivity of the physiograph, test organisms were chosen which ranged in size from 57 to 105 mm total length.

"Cough" response tests were usually conducted concurrently with avoidance tests. One fish was placed in each chamber and subjected to a continuous flow of untreated water for approximately 48 hrs. If turbidity was high this period was shortened to 24 hrs. During this time the fish were allowed to acclimate to the test chamber and to establish a normal respiratory pattern. Physiographic traces of this pattern were made just prior to the exposure period for comparison with traces taken during exposure periods. Traces were then taken at concentrations which were gradually increased to levels beyond the avoidance concentration. Traces for fish in untreated water were taken simultaneously with each biocide concentration to compare differences in cough rate, breathing and behavior of the fish. Exposure to a concentration was from 5 to 45 minutes before a trace was taken and depended on the species and behavior of the fish. The fish were given ample time to adjust to the increase in concentration. This permitted better observations and enabled the physiograph to record distinct "coughs" in the respiratory pattern without interference from excessive activity. A five minute trace was taken at each concentration. Observed and physiographic (traced) "coughs" were used to calculate "coughs" per minute (CPM) at each concentration. However, sometimes only one of these procedures was used if poor visibility made observations difficult, or if "coughs" could not be recorded by the physiograph.

Biocide concentrations were determined throughout each test. Water temperature and dissolved oxygen were measured after each test. Salinity and pH were determined at the beginning and the end of each test. Test organisms were measured, and in some cases weighed and examined.

Test Organisms

Most of the test organisms used in the study were collected from the watersheds of the Delaware River and upper Chesapeake Bay drainages by seine and transported to the laboratory in insulated holding vessels. Only a few test organisms used at Bergen were taken from Overpeck Creek due to the paucity of specimens. Rainbow trout were obtained from the aquaculture facility at the Mercer Generating Station.

Tests were conducted at Bergen with silvery minnow, Hybognathus nuchalis; spottail shiner, Notropis hudsonius; mummichog, Fundulus heteroclitus, tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio. Tests at Mercer were conducted with blueback herring, Alosa aestivalis; alewife, Alosa pseudoharengus; rainbow trout, Salmo gairdneri; satinfin shiner, Notropis analostanus; spottail shiner, Notropis hudsonius; banded killifish, Fundulus diaphanus; and white perch, Morone americana. Test organisms were fed a variety of foods but not during or 24 hours prior to testing.

Water Chemistry

Water temperature was measured with hand-held immersion thermometers scaled in 1.0 C intervals. The level of dissolved oxygen was measured with a YSI Model 57 temperature compensated oxygen meter having a precision of 0.05 mg/l (on the 0-5 scale), 0.10 mg/l (on the 0-10 scale), and 0.20 mg/l (on the 0-20 scale). Dissolved oxygen readings were calibrated against 100% air saturation values corrected for temperature and salinity. A Corning Model 610 A pH meter having a precision of 0.1 pH units was used to measure pH. The meter was calibrated by means of buffer solutions. Salinity was measured with a YSI Model 33-S-C-T meter having a precision of 0.2 ppt.

Biocide Measurements. Chlorine residuals were determined using a Wallace and Tiernan amperometric titrator according to Method 409 C in Standard Methods for the Examination of Water and Wastewater (9). It is important to note that, as a result of the different water quality conditions at Bergen and Mercer, chlorine produces a different set of oxidant species at each site. Considering salinity, pH and amino-nitrogen, the following oxidant species are most probably produced by chlorine (6,10):

Bergen - chloramines, organic chloramines and traces of bromamines;
Mercer - free chlorine and chloramines.

Free chlorine, as operationally defined by Method 409 C was rarely detected at Bergen and accounted for only a fraction of the total chlorine at Mercer.

Ozone was to be measured using the same procedure as for total chlorine (amperometric titration at pH 4). However, when dosed with ozone, the river water at Bergen did not reveal any residual when measured at pH 4. It was found that a measurable residual did exist when analyzed at pH 2. Routine analysis of this ozone produced oxidant was therefore carried out using amperometric titration at pH 2.

Further testing for ozone at Bergen corroborated the finding that the residual being measured at pH 2 was an unidentified oxidative by-product of ozone and not ozone itself (6).

In contrast to Bergen, ozonation of the river water at Mercer did produce an ozone residual which could be measured by amperometric titration at pH 4 or at pH 2. Analysis at pH 2 included a natural background which had to be subtracted from each determination. No background was measured at pH 4; the background at pH 2 accounted for any differences in the results at pH 2 and pH 4 at Mercer.

In addition, it is important to note that the ozone residuals reported here are measured as mg/l chlorine. Conversion of these results to mg/l ozone requires multiplication by a factor of 0.68.

Section 3

RESULTS AND DISCUSSION

WATER CHEMISTRY

Studies at Bergen were conducted with test temperatures from 14.5-31.5 C, salinities from 0.2-2.5 ppt, levels of dissolved oxygen from 2.7-greater than 20 mg/l and pH from 6.7-7.6. Studies at Mercer were conducted in freshwater with test temperatures from 2-28 C, levels of dissolved oxygen from 5.8-greater than 20 mg/l, and pH from 7.0-8.4.

TOXICITY STUDIES

Acute (96-hr) toxicity tests at Bergen were conducted with silvery minnow, Hybognathus nuchalis; spottail shiner, Notropis hudsonious; mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio. Silvery minnow and spottail shiner were subjected only to ozone. Acute (96-hr) toxicity tests at Mercer were conducted with blueback herring, Alosa aestivalis; alewife, Alosa pseudoharengus; rainbow trout, Salmo gairdneri; spottail shiner, Notropis hudsonius; satinfin shiner, Notropis analostanus; and white perch, Morone americana. Satinfin shiner was subjected only to chlorine.

During February, 1979, toxicity tests of chlorine and ozone at Bergen were conducted with mummichog using continuous flow-through conditions. In the chlorine tests the control group experienced 70% mortality, identical to that in the highest chlorine concentration (0.04 mg/l). Mortality in the control group for the ozone test was 40%. Although the level of dissolved oxygen was low (3.8 mg/l average) the mortalities were likely due to an unexplained characteristic of water quality.

Mummichog in both control and experimental groups had hemorrhaging and aneurisms in the gills. When placed in the untreated (no biocide) test water, fish immediately went to the bottom of the test tank. After two hours they came to surface "gulping air" and shortly thereafter lost equilibrium. Based on these tests, the procedure was modified from the continuous flow-through to a static aerated condition as previously described.

Subsequent toxicity testing at Bergen was directed at determining which species could be tested (using the static aerated procedure) under the conditions of adverse water quality in Overpeck Creek. Species tested for suitability included: blueback herring, mummichog, silvery minnow, white perch, and grass shrimp. All with the exception of blueback herring, were deemed suitable for testing. Therefore, during March, 1979, toxicity tests at Bergen were conducted using the static aerated procedure. At Mercer, no problems were encountered with mortalities resulting from water quality.

Chlorine toxicity

Bergen. Results of toxicity tests with chlorine at Bergen are given in Table 1. Cumulative mortalities over the 4-, 24-, 48-, 72-, and 96-hr periods are given in Table 2. Percent mortality at 96 hours at each respective test concentration of total chlorine is plotted for mummichog, tidewater silverside, white perch, and grass shrimp in Figures 5-8.

Chlorine toxicity tests with mummichog and tidewater silverside were conducted at a test temperature of 19 C and salinity of 0.5 ppt. White perch and grass shrimp were tested at 14.5 C and 1 ppt. Concentrations of total chlorine below 0.40 mg/l did not result in mortality with mummichog but 100% mortality occurred in 0.08 mg/l with tidewater silverside, at 0.70 mg/l with mummichog, and at 0.37 mg/l with white perch. However, a concentration of 0.37 mg/l caused only 10% mortality with grass shrimp and 0.63 mg/l resulted in 40% mortality. Unexpectedly, 0.87 mg/l did not cause any mortality with grass shrimp.

Table 1

Results of toxicity tests with chlorine for mummichog, *Fundulus heteroclitus*; tidewater silverside, *Menidia beryllina*; white perch, *Morone americana*; and grass shrimp, *Palaemonetes pugio*; conducted at Bergen. (*=level of chlorine undetectable)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
FUNDULUS HETEROCLITUS													
12 FEB 79	43.8	1	16	3.8	7.4	*	0	10	-	-	9	-	-
							4	10	0	0	9	0	0
							24	5	5	5	6	3	6
							48	4	6	4	5	4	5
							72	4	6	4	4	5	4
							90	3	7	3	4	5	4
12 FEB 79	41.2	1	16	3.8	7.4	*	0	10	-	-	10	-	-
							4	10	0	0	10	0	0
							24	5	5	5	7	3	5
							48	4	6	4	6	4	6
							72	4	6	4	6	4	6
							90	3	7	3	3	7	3
12 FEB 79	39.7	1	16	3.8	7.4	*	0	10	-	-	10	-	-
							4	10	0	0	10	0	0
							24	5	5	5	4	6	4
							48	4	6	4	3	7	3
							72	4	6	4	2	8	2
							90	3	7	3	2	8	2
12 FEB 79	41.4	1	16	3.8	7.4	0.01	0	10	-	-	9	-	-
							4	10	0	0	9	0	0
							24	5	5	5	5	4	5
							48	4	6	4	5	4	5
							72	4	6	4	4	5	4
							90	3	7	3	4	5	4
12 FEB 79	39.3	1	16	3.8	7.4	0.04	0	10	-	-	9	-	-
							4	10	0	0	9	0	0
							24	5	5	5	6	3	6
							48	4	6	4	3	6	3
							72	4	6	4	2	7	2
							90	3	7	3	2	7	2
20 MAR 79	64.4	0.5	19	5	7.4	0.01	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	69.6	0.5	19	4.5	7.4	0.04	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	67.8	0.5	19	6	7.4	0.09	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	68.9	0.5	19	6	7.4	0.4	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	62.5	0.5	19	3.8	7.4	0.7	0	10	-	-	10	-	-
							1.25	10	0	0	8	2	3
							1.5	10	0	0	6	4	4
							2	10	0	0	1	9	1
							3.5	10	0	0	0	10	0
20 MAR 79	68.2	0.5	19	3.4	7.4	1	0	10	-	-	10	-	-
							1	10	0	0	10	0	1
							1.3	10	0	0	5	5	2
							1.5	10	0	0	4	6	1
							2	10	0	0	2	8	0
							2.5	10	0	0	0	10	0

Table 1 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
MENIDIA BERYLLINA													
20 MAR 79	45	0.5	19	5.9	7.4	0.08	0	5	-	-	5	-	-
							2.5	5	0	0	4	1	0
							20.5	5	0	0	3	2	0
							44.5	5	0	0	2	3	0
							50	5	0	0	1	4	0
							75	5	0	0	0	5	0
20 MAR 79	48.6	0.5	19	6.1	7.4	0.46	0	5	-	-	5	-	-
							0.6	5	0	0	4	1	3
							0.9	5	0	0	0	5	0
20 MAR 79	50.2	0.5	19	5.7	7.4	0.95	0	5	-	-	5	-	-
							0.6	5	0	0	0	5	0
MORONE AMERICANA													
27 MAR 79	153.6	1	14.5	6.2	7.5	0.02	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
27 MAR 79	154.4	1	14.5	6.7	7.5	0.12	0	5	-	-	5	-	-
							24	5	0	0	4	1	0
							45	5	0	0	3	2	0
							69	5	0	0	2	3	0
							96	5	0	0	2	3	0
27 MAR 79	156.2	1	14.5	6.7	7.5	0.37	0	5	-	-	5	-	-
							1.5	5	0	0	1	4	1
							24	5	0	0	0	5	0
27 MAR 79	159	1	14.5	6.6	7.5	0.63	0	5	-	-	5	-	-
							1.5	5	0	0	0	5	0
27 MAR 79	156	1	14.5	7	7.5	0.87	0	5	-	-	5	-	-
							1.5	5	0	0	0	5	0
PALAEMONETES PUGIO													
27 MAR 79	26.7	1	14.5	6.2	7.5	0.02	0	10	-	-	10	-	-
							43	10	0	0	9	1	0
							96	10	0	0	9	1	0
27 MAR 79	27	1	14.5	6.7	7.5	0.12	0	10	-	-	10	-	-
							1.5	10	0	0	9	1	0
							96	10	0	0	9	1	0
27 MAR 79	25.6	1	14.5	6.7	7.5	0.37	0	10	-	-	10	-	-
							43	10	0	0	9	1	0
							96	10	0	0	9	1	0
27 MAR 79	26.2	1	14.5	6.6	7.5	0.63	0	10	-	-	10	-	-
							18	10	0	0	9	1	0
							67	10	0	0	8	2	0
							69	10	0	0	7	3	0
							96	10	0	0	6	4	0
27 MAR 79	25.7	1	14.5	7	7.5	0.87	0	10	-	-	10	-	-
							96	10	0	0	10	0	0

Table 2

Chronological summary of toxicity tests with chlorine for mummichog, *Fundulus heteroclitus*; tidewater silverside, *Menidia beryllina*; white perch, *Morone americana*; and grass shrimp, *Palaemonetes pugio*; conducted at Bergen. (*=level of chlorine undetectable)

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	TOT. CL2 (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
FUNDULUS HETEROCLITUS														
12 FEB 79	37	56	43.8	1	7.4	3.8	16	*	9	0	33	44	56	-
12 FEB 79	32	45	41.2	1	7.4	3.8	16	*	10	0	30	40	40	-
12 FEB 79	31	51	39.7	1	7.4	3.8	16	*	10	0	60	70	80	-
12 FEB 79	33	55	41.4	1	7.4	3.8	16	0.01	9	0	44	44	56	-
12 FEB 79	32	47	39.3	1	7.4	3.8	16	0.04	9	0	33	67	78	-
20 MAR 79	57	74	64.4	0.5	7.4	5	19	0.01	10	0	0	0	0	0
20 MAR 79	59	92	69.6	0.5	7.4	4.5	19	0.04	10	0	0	0	0	0
20 MAR 79	56	104	67.8	0.5	7.4	6	19	0.09	10	0	0	0	0	0
20 MAR 79	57	84	68.9	0.5	7.4	6	19	0.4	10	0	0	0	0	0
20 MAR 79	54	73	62.5	0.5	7.4	3.8	19	0.7	10	100	100	100	100	100
20 MAR 79	57	94	68.2	0.5	7.4	3.4	19	1	10	100	100	100	100	100
MENIDIA BERYLLINA														
20 MAR 79	39	56	45	0.5	7.4	5.9	19	0.08	5	20	40	60	80	100
20 MAR 79	41	60	48.6	0.5	7.4	6.1	19	0.46	5	100	100	100	100	100
20 MAR 79	44	62	50.2	0.5	7.4	5.7	19	0.95	5	100	100	100	100	100
MORONE AMERICANA														
27 MAR 79	135	172	153.6	1	7.5	6.2	14.5	0.02	5	0	0	0	0	0
27 MAR 79	137	170	154.4	1	7.5	6.7	14.5	0.12	5	0	20	40	60	60
27 MAR 79	132	174	156.2	1	7.5	6.7	14.5	0.37	5	80	100	100	100	100
27 MAR 79	139	170	159	1	7.5	6.6	14.5	0.63	5	100	100	100	100	100
27 MAR 79	150	166	156	1	7.5	7	14.5	0.87	5	100	100	100	100	100
PALAEMONETES PUGIO														
27 MAR 79	23	32	26.7	1	7.5	6.2	14.5	0.02	10	0	0	10	10	10
27 MAR 79	21	34	27	1	7.5	6.7	14.5	0.12	10	10	10	10	10	10
27 MAR 79	22	30	25.6	1	7.5	6.7	14.5	0.37	10	0	0	10	10	10
27 MAR 79	20	33	26.2	1	7.5	6.6	14.5	0.63	10	0	10	10	30	40
27 MAR 79	22	32	25.7	1	7.5	7	14.5	0.87	10	0	0	0	0	0

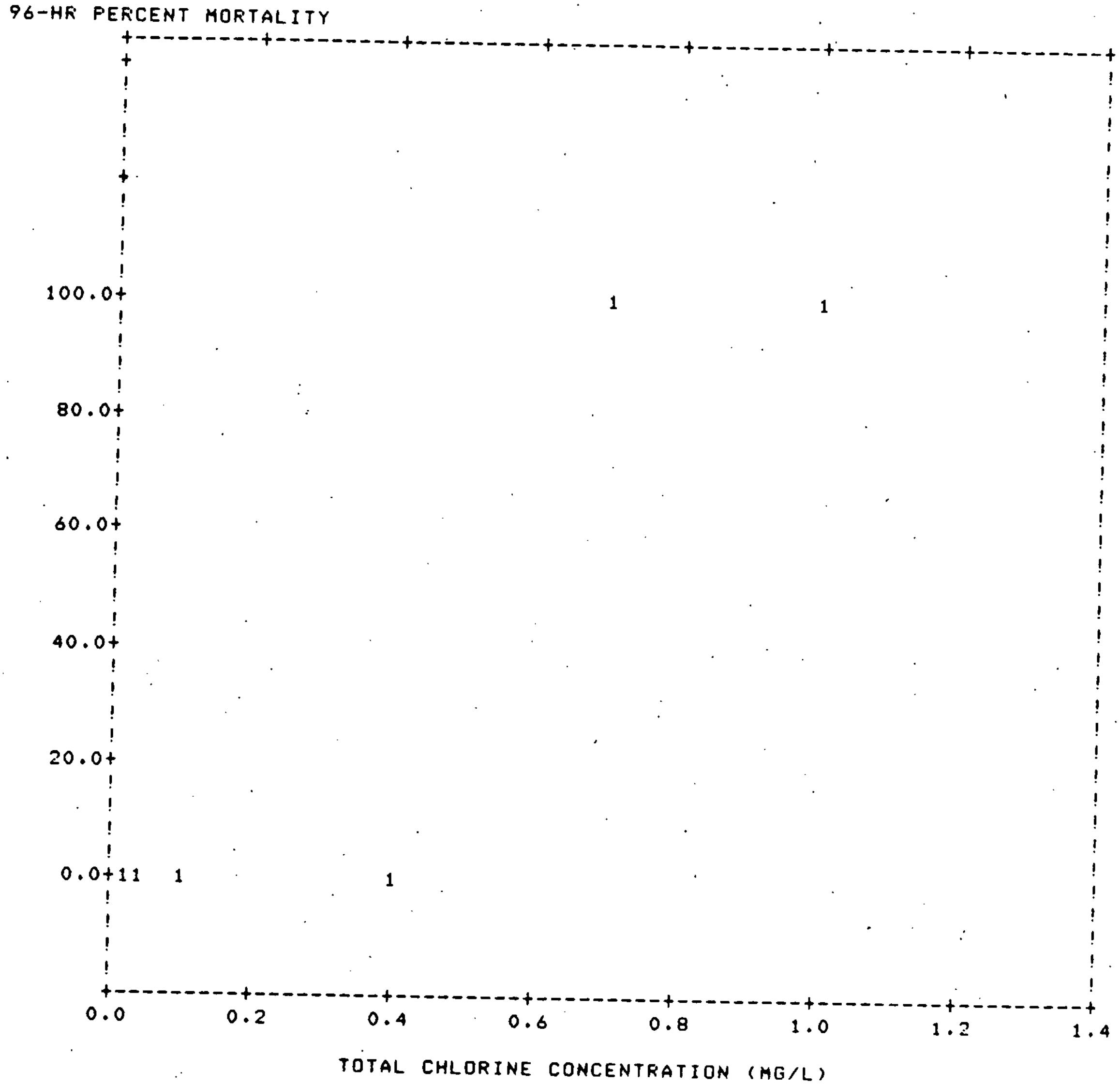


Figure 5. 96-hour percent mortality of the mummichog, Fundulus heteroclitus, for two-hour daily exposure to total chlorine at Bergen.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.54 mg/l total chlorine.
3. Test temperature was 19 C.

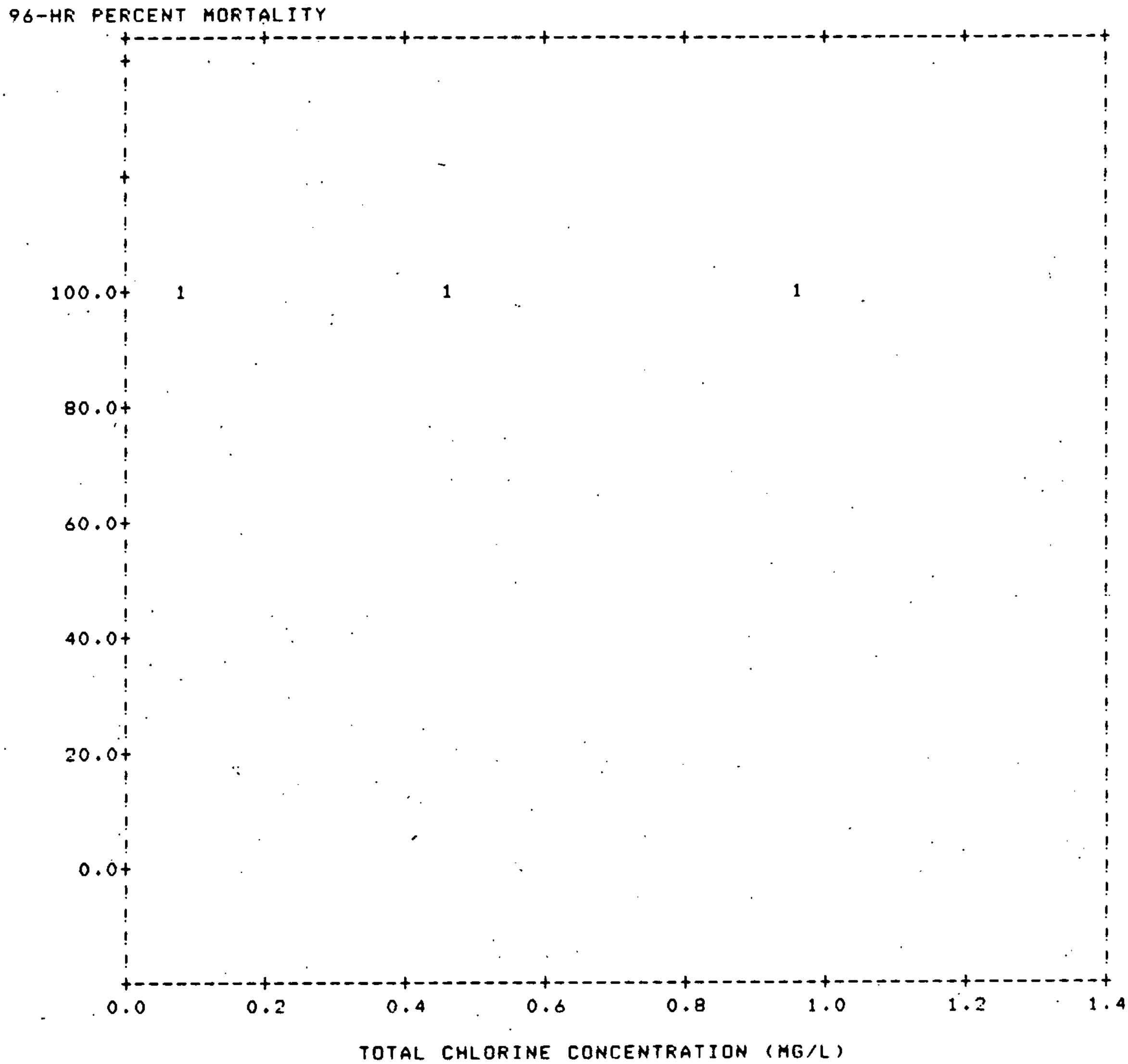


Figure 6. 96-hour percent mortality of the tidewater silverside, Menidia beryllina, for two-hour daily exposures to total chlorine at Bergen.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 19 C.

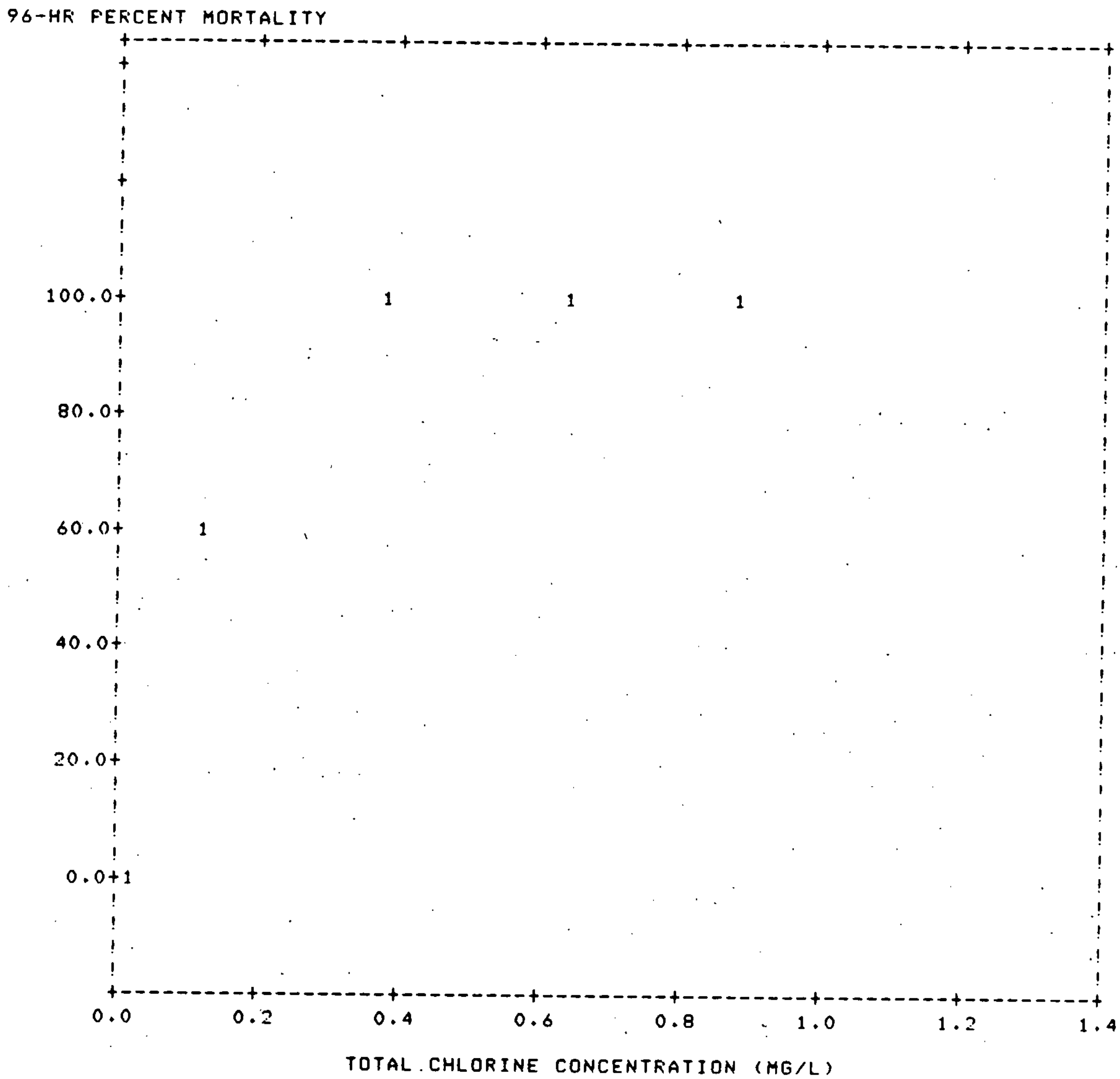


Figure 7. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to total chlorine at Bergen.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.1 mg/l total chlorine.
3. Test temperature was 14.5 C.

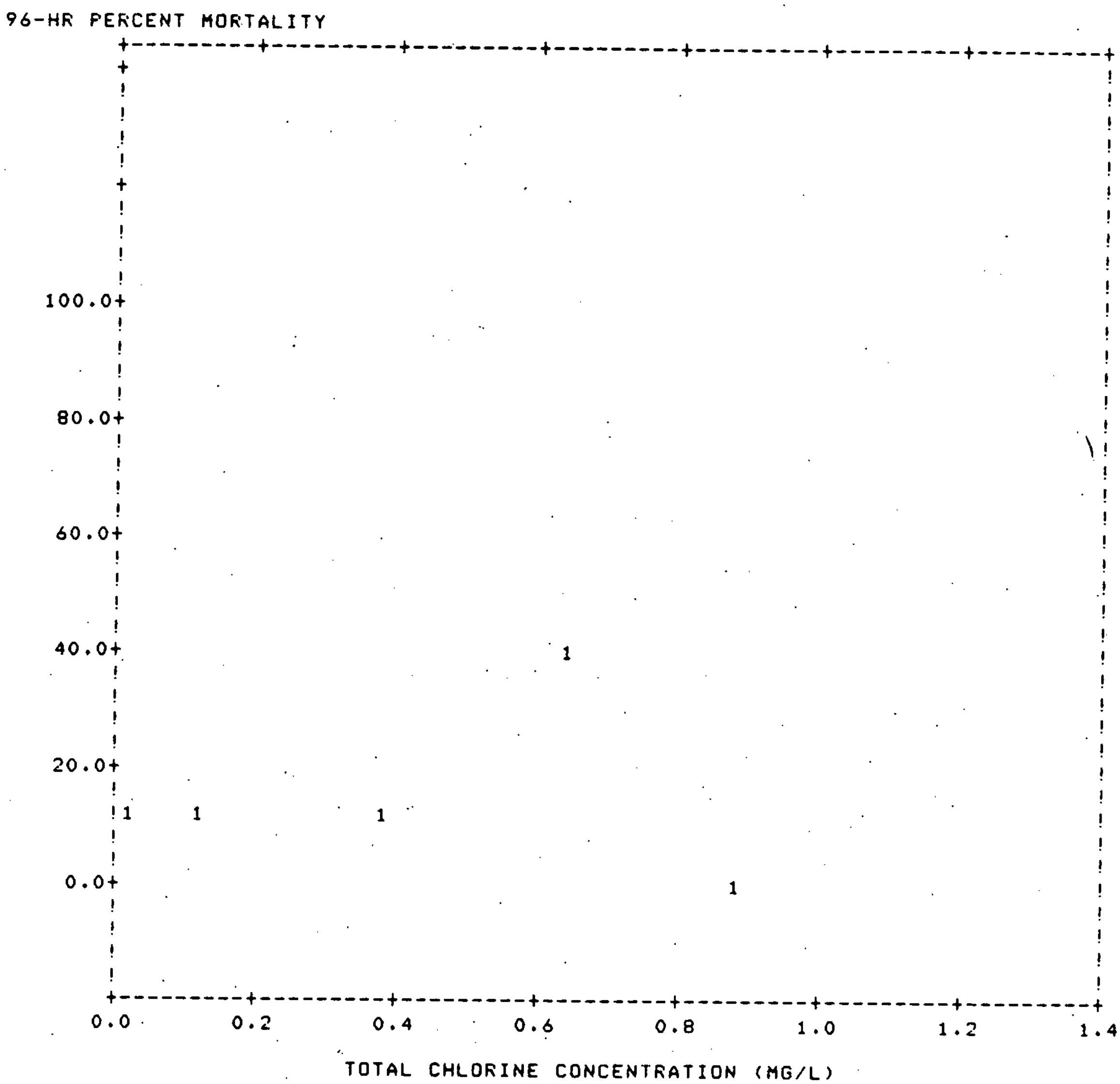


Figure 8. 96-hour percent mortality of the grass shrimp, _Palaemonetes pugio_, for two-hour daily exposures to total chlorine at Bergen.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 14.5 C.

The 96-hour LC_{50} for a 2-hour intermittent exposure ($ICL_{50(96,2)}$) for mummichog tested at 19 C was about 0.54 mg/l total chlorine. That for white perch tested at 14.5 C was about 0.10 mg/l total chlorine. The $ILC_{50(96,2)}$ values for tidewater silverside and grass shrimp could not be determined because no available concentrations resulted in at least 50% mortality with grass shrimp and less than 100% mortality with tidewater silverside.

Mercer: Results of toxicity tests with chlorine at Mercer are given in Table 3. Cumulative mortalities over the 4-, 24-, 48-, 72-, and 96-hr periods are given in Table 4. The test with blueback herring (Figure 9) and one test with white perch, conducted at an average temperature of about 2 C, were not evaluated due to unacceptable (greater than 20%) control mortality.

Alewife were tested at an average temperature of about 22 C and at concentrations of total chlorine between 0.14-0.89 mg/l. Percent mortality at 96 hours at each respective test concentration of total chlorine is plotted for alewife in Figure 10. The $ILC_{50(96,2)}$ for alewife was about 0.27 mg/l total chlorine.

Rainbow trout were tested at an average temperature of about 5 C and at concentrations of total chlorine between 0.12-0.81 mg/l. Percent mortality at 96 hours at each respective test concentration of total chlorine is plotted for rainbow trout in Figure 11. The $ILC_{50(96,2)}$ for rainbow trout was about 0.67 mg/l total chlorine.

Spottail shiner were tested at average temperatures of about 6 and 26 C and at concentrations of total chlorine between 0.07-1.26 mg/l. Percent mortality at 96 hours at each respective test concentration is plotted for spottail shiner in Figure 12. At 6 C, no mortality occurred at 0.07 mg/l total chlorine and only 33% mortality occurred at 0.28 mg/l total chlorine (the highest concentration tested). At 26 C, the $ILC_{50(96,2)}$ for spottail shiner was about 0.35 mg/l total chlorine.

Satinfin shiner tested at about 6 C experienced 100% mortality at 0.52 mg/l total chlorine (the only concentration tested).

Table 3

Results of toxicity tests with chlorine for blueback herring, *Alosa aestivalis*; alewife, *Alosa pseudoharengus*; rainbow trout, *Salmo gairdneri*; spottail shiner, *Notropis hudsonius*; satinfin shiner, *Notropis analostanus*; and white perch, *Morone americana*; conducted at Mercer.

								CONTROL			EXPERIMENTAL		
DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	NO. ALIVE	NO. DEAD	NO. WITH L.O.E.	NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
ALOSA AESTIVALIS													
11 DEC 79	66.7	0	5.9	10.8	7.8	0.07	0	10	-	-	10	-	-
							23.25	9	1	0	10	0	0
							45.5	9	1	0	9	1	0
							51.75	8	2	0	8	2	0
							69	7	3	0	8	2	1
							96	7	3	0	7	3	0
11 DEC 79	73.3	0	5.9	10.9	7.8	0.13	0	10	-	-	10	-	-
							23.25	9	1	0	10	0	0
							24	9	1	0	9	1	0
							45.5	9	1	0	8	2	0
							72	7	3	0	6	4	0
							96	7	3	0	5	5	0
11 DEC 79	68.7	0	6.3	10.9	7.8	0.28	0	10	-	-	10	-	-
							23.25	9	1	0	10	0	0
							29.75	9	1	0	9	1	0
							48	9	1	0	8	2	1
							50	9	1	1	7	3	0
							96	7	3	0	5	5	0
11 DEC 79	66.3	0	6.3	10.9	7.7	0.4	0	10	-	-	10	-	-
							21	10	0	1	6	4	0
							23.25	9	1	0	6	4	0
							45.5	9	1	0	5	5	0
							69	7	3	0	4	6	0
							96	7	3	0	1	9	0
11 DEC 79	72.9	0	6.3	11	7.6	0.52	0	10	-	-	10	-	-
							21	10	0	1	7	3	2
							23.25	9	1	0	6	4	1
							24.75	9	1	0	5	5	1
							48	9	1	0	2	8	0
							96	7	3	0	0	10	0
ALOSA PSEUDOHARENGUS													
9 JUN 80	29.4	0	21.2	8	7.3	0.14	0	10	-	-	10	-	-
							18.25	10	0	0	9	1	0
							49.75	9	1	0	9	1	0
							90.5	8	2	0	8	2	0
							96	8	2	0	8	2	0
9 JUN 80	31.6	0	22	7.9	7.2	0.48	0	10	-	-	10	-	-
							1.75	10	0	0	9	1	0
							2.33	10	0	0	7	3	0
							2.75	10	0	0	6	4	0
							3.25	10	0	0	5	5	1
							18.25	10	0	0	0	10	0
9 JUN 80	28.8	0	24	8.7	7.2	0.89	0	10	-	-	10	-	-
							0.75	10	0	0	2	8	0
							0.83	10	0	0	1	9	1
							0.92	10	0	0	0	10	0
SALMO GAIRDNERI													
24 MAR 80	159.2	0	5.3	11.4	7.9	0.12	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
24 MAR 80	150.6	0	5.3	11.4	7.9	0.23	0	5	-	-	5	-	-
							96	5	0	0	5	0	0

Table 3 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
SALMO GAIRDNERI													
24 MAR 80	165.4	0	5.4	11.5	7.9	0.42	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
24 MAR 80	159.4	0	5.5	11.5	7.9	0.6	0	5	-	-	5	-	-
							75	5	0	0	5	0	1
							91.25	5	0	0	4	1	0
							96	5	0	0	4	1	0
24 MAR 80	158	0	5.3	11.7	7.8	0.81	0	5	-	-	5	-	-
							2.75	5	0	0	4	1	0
							6.25	5	0	0	3	2	0
							50.5	5	0	0	2	3	1
							67.25	5	0	0	1	4	0
							73	5	0	0	0	5	0
NOTROPIS HUDSONIUS													
11 DEC 79	84.5	0	5.9	10.8	7.8	0.07	0	2	-	-	2	-	-
							96	2	0	0	2	0	0
11 DEC 79	64.3	0	6.3	10.9	7.8	0.28	0	2	-	-	3	-	-
							52.25	2	0	0	3	0	1
							69	2	0	0	2	1	0
							96	2	0	0	2	1	0
7 JUL 80	36.5	0	25.9	7	7.4	0.1	0	10	-	-	8	-	-
							17	10	0	0	7	1	0
							41	10	0	0	6	2	0
							96	10	0	0	6	2	0
7 JUL 80	36.1	0	26	7.3	7.4	0.22	0	10	-	-	10	-	-
							0.33	10	0	0	10	0	1
							1.17	10	0	0	9	1	0
							1.42	10	0	0	8	2	0
							2.25	10	0	0	7	3	0
							96	10	0	0	7	3	0
7 JUL 80	33.4	0	25.5	9.2	7.8	0.64	0	10	-	-	10	-	-
							0.42	10	0	0	10	0	1
							0.5	10	0	0	7	3	3
							0.67	10	0	0	3	7	2
							0.75	10	0	0	1	9	1
							1.17	10	0	0	0	10	0
7 JUL 80	34.5	0	25.5	9.8	7.8	0.91	0	10	-	-	10	-	-
							0.17	10	0	0	10	0	4
							0.33	10	0	0	4	6	2
							0.42	10	0	0	3	7	2
							0.5	10	0	0	2	8	2
							0.67	10	0	0	0	10	0
7 JUL 80	34	0	25.5	10.2	7.6	1.26	0	10	-	-	9	-	-
							0.17	10	0	0	9	0	5
							0.33	10	0	0	4	5	2
							0.42	10	0	0	4	5	3
							0.5	10	0	0	1	8	1
							0.67	10	0	0	0	9	0
NOTROPIS ANALOSTANUS													
11 DEC 79	49	0	6.3	11	7.6	0.52	0	1	-	-	1	-	-
							96	1	0	0	0	1	0

Table 3 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
MORONE AMERICANA													
17 DEC 79	67.8	0	1.8	12.3	8	0.1	0	10	-	-	9	-	-
							19.5	10	0	0	9	0	1
							27.5	10	0	0	8	1	0
							44.5	9	1	0	7	2	1
							70	7	3	3	5	4	1
							96	3	7	1	3	6	1
17 DEC 79	64.3	0	1.8	12.5	8	0.19	0	10	-	-	10	-	-
							26.5	10	0	0	10	0	1
							44.5	9	1	0	7	3	0
							67.5	8	2	4	6	4	1
							75	6	4	2	5	5	3
							96	3	7	1	1	9	1
17 DEC 79	61.5	0	2.1	12.5	8	0.36	0	10	-	-	10	-	-
							19.5	10	0	0	9	1	2
							28	10	0	0	8	2	3
							44.5	9	1	0	3	7	1
							47	9	1	1	2	8	1
							67.5	8	2	4	0	10	0
17 DEC 79	62.6	0	2.4	12.5	8	0.53	0	10	-	-	10	-	-
							19.5	10	0	0	7	3	3
							22.5	10	0	0	5	5	1
							25.75	10	0	0	4	6	1
							44.5	9	1	0	1	9	1
							50	9	1	1	0	10	0
17 DEC 79	62.8	0	2.5	13	8	0.73	0	10	-	-	10	-	-
							19.5	10	0	0	3	7	2
							25	10	0	0	2	8	1
							26.5	10	0	0	2	8	2
							27.5	10	0	0	1	9	1
							44.5	9	1	0	0	10	0
7 JAN 80	148.2	0	2	11.6	8.1	0.1	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 JAN 80	161	0	2	11.6	8.1	0.2	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 JAN 80	157	0	2	11.7	8.1	0.4	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 JAN 80	149.8	0	2.1	11.8	8.1	0.6	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 JAN 80	158.6	0	2.2	11.9	8.1	0.78	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 APR 80	152.8	0	11.3	10	7.5	0.19	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 APR 80	160.2	0	11.4	10	7.5	0.36	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
7 APR 80	160	0	11.4	10	7.5	0.77	0	5	-	-	5	-	-
							74	5	0	0	5	0	1
							91.5	5	0	0	4	1	0
							96	5	0	0	4	1	0
7 APR 80	167.8	0	11.4	10	7.5	1.12	0	5	-	-	5	-	-
							2	5	0	0	5	0	3
							2.5	5	0	0	4	1	2
							3.25	5	0	0	2	3	0
							26.25	5	0	0	1	4	0
							91.5	5	0	0	0	5	0

Table 3 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL			EXPERIMENTAL		
								NO. ALIVE	NO. DEAD	NO. WITH L.O.E.	NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
MORONE AMERICANA													
7 APR 80	173.4	0	11.1	9.9	7.5	1.49	0	5	-	-	5	-	-
							1.25	5	0	0	5	0	4
							1.5	5	0	0	5	0	5
							1.75	5	0	0	2	3	2
							2.5	5	0	0	1	4	1
							7.5	5	0	0	0	5	0
19 MAY 80	145.6	0	19.1	7.6	7.2	0.16	0	5	-	-	5	-	-
							44	4	1	0	5	0	0
							96	4	1	0	5	0	0
19 MAY 80	149.4	0	19.1	7.5	7.2	0.28	0	5	-	-	5	-	-
							44	4	1	0	5	0	0
							96	4	1	0	5	0	0
19 MAY 80	142.4	0	19.1	7.6	7.2	0.63	0	5	-	-	5	-	-
							2.5	5	0	0	5	0	2
							3.25	5	0	0	4	1	1
							6.5	5	0	0	3	2	0
							44	4	1	0	3	2	0
							96	4	1	0	3	2	0
19 MAY 80	141	0	19	7.3	7.1	0.97	0	5	-	-	5	-	-
							1	5	0	0	5	0	1
							1.25	5	0	0	4	1	1
							1.33	5	0	0	3	2	1
							1.75	5	0	0	1	4	1
							2.25	5	0	0	0	5	0
19 MAY 80	142.6	0	19	7.3	7	1.29	0	5	-	-	5	-	-
							0.5	5	0	0	5	0	1
							0.75	5	0	0	4	1	2
							1.08	5	0	0	2	3	1
							1.17	5	0	0	1	4	0
							2	5	0	0	0	5	0
9 JUN 80	87	0	21.2	8	7.3	0.14	0	10	-	-	10	-	-
							90.5	10	0	2	9	1	0
							96	8	2	0	9	1	0
9 JUN 80	82.7	0	21.3	8.1	7.2	0.26	0	10	-	-	10	-	-
							90.5	10	0	2	10	0	0
							96	8	2	0	10	0	0
9 JUN 80	80	0	21.4	8.1	7.2	0.52	0	10	-	-	9	-	-
							26.33	10	0	0	9	0	1
							42.5	10	0	0	8	1	0
							90.5	10	0	2	8	1	0
							96	8	2	0	8	1	0
9 JUN 80	86	0	22	7.9	7.2	0.72	0	10	-	-	10	-	-
							1.33	10	0	0	8	2	1
							1.5	10	0	0	6	4	0
							2	10	0	0	4	6	0
							2.75	10	0	0	2	8	0
							18.5	10	0	0	0	10	0
9 JUN 80	83.7	0	24	8.7	7.2	0.93	0	10	-	-	9	-	-
							0.67	10	0	0	8	1	0
							1	10	0	0	6	3	2
							1.17	10	0	0	5	4	2
							1.33	10	0	0	2	7	1
							1.75	10	0	0	0	9	0
7 JUL 80	143	0	25.9	7	7.4	0.1	0	5	-	-	5	-	-
							89.25	5	0	0	3	2	0
							94	4	1	0	3	2	0
							96	4	1	0	3	2	0

Table 3 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	CL2 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
MORONE AMERICANA													
7 JUL 80	137.2	0	26	7.3	7.4	0.22	0	5	-	-	5	-	-
							94	4	1	0	5	0	0
							96	4	1	0	5	0	0
7 JUL 80	135.6	0	26.1	7.6	7.4	0.62	0	5	-	-	5	-	-
							92.75	5	0	0	5	0	1
							93	5	0	0	4	1	0
							94	4	1	0	4	1	0
							96	4	1	0	4	1	0
7 JUL 80	152	0	26.1	7.7	7.4	0.83	0	5	-	-	5	-	-
							41.25	5	0	0	4	1	0
							65.25	5	0	0	3	2	0
							68.5	5	0	0	2	3	0
							94	4	1	0	1	4	0
							96	4	1	0	1	4	0
7 JUL 80	147	0	25.8	7.9	7.2	1.09	0	5	-	-	5	-	-
							1.42	5	0	0	4	1	2
							1.75	5	0	0	3	2	2
							2	5	0	0	2	3	1
							2.17	5	0	0	1	4	0
							70.75	5	0	0	0	5	0

Table 4

Chronological summary of toxicity tests with chlorine for blueback herring, *Alosa aestivalis*; alewife, *Alosa pseudoharengus*; rainbow trout, *Salmo gairdneri*; spottail shiner, *Notropis hudsonius*; satinfin shiner, *Notropis analostanus*; and white perch, *Morone americana*; conducted at Mercer.

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	TOT. CL2 (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
ALOSA AESTIVALIS														
11 DEC 79	55	75	66.7	0	7.8	10.8	5.9	0.07	10	0	0	10	20	30
11 DEC 79	65	75	73.3	0	7.8	10.9	5.9	0.13	10	0	10	20	40	50
11 DEC 79	59	84	68.7	0	7.8	10.9	6.3	0.28	10	0	0	20	30	50
11 DEC 79	48	82	66.3	0	7.7	10.9	6.3	0.4	10	0	40	50	60	90
11 DEC 79	61	90	72.9	0	7.6	11	6.3	0.52	10	0	40	80	80	100
ALOSA PSEUDOHARENGUS														
9 JUN 80	24	32	29.4	0	7.3	8	21.2	0.14	10	0	10	10	10	20
9 JUN 80	28	34	31.6	0	7.2	7.9	22	0.48	10	50	100	100	100	100
9 JUN 80	26	33	28.8	0	7.2	8.7	24	0.89	10	100	100	100	100	100
SALMO GAIRDNERI														
24 MAR 80	155	167	159.2	0	7.9	11.4	5.3	0.12	5	0	0	0	0	0
24 MAR 80	139	167	150.6	0	7.9	11.4	5.3	0.23	5	0	0	0	0	0
24 MAR 80	150	180	165.4	0	7.9	11.5	5.4	0.42	5	0	0	0	0	0
24 MAR 80	129	173	159.4	0	7.9	11.5	5.5	0.6	5	0	0	0	0	20
24 MAR 80	149	170	158	0	7.8	11.7	5.3	0.81	5	20	40	40	80	100
NOTROPIS HUDSONIUS														
11 DEC 79	84	85	84.5	0	7.8	10.8	5.9	0.07	2	0	0	0	0	0
11 DEC 79	60	68	64.3	0	7.8	10.9	6.3	0.28	3	0	0	0	33	33
7 JUL 80	30	44	36.5	0	7.4	7	25.9	0.1	8	0	13	25	25	25
7 JUL 80	31	40	36.1	0	7.4	7.3	26	0.22	10	30	30	30	30	30
7 JUL 80	30	39	33.4	0	7.8	9.2	25.5	0.64	10	100	100	100	100	100
7 JUL 80	30	40	34.5	0	7.8	9.8	25.5	0.91	10	100	100	100	100	100
7 JUL 80	28	38	34	0	7.6	10.2	25.5	1.26	9	100	100	100	100	100
NOTROPIS ANALOSTANUS														
11 DEC 79	-	-	49	0	7.6	11	6.3	0.52	1	0	0	0	0	100
MORONE AMERICANA														
17 DEC 79	58	80	67.8	0	8	12.3	1.8	0.1	9	0	0	22	44	67
17 DEC 79	58	73	64.3	0	8	12.5	1.8	0.19	10	0	0	30	40	90
17 DEC 79	50	80	61.5	0	8	12.5	2.1	0.36	10	0	10	80	100	100
17 DEC 79	50	77	62.6	0	8	12.5	2.4	0.53	10	0	50	90	100	100
17 DEC 79	50	75	62.8	0	8	13	2.5	0.73	10	0	70	100	100	100

Table 4 (continued)

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	TOT. CL2 (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
MORONE AMERICANA														
7 JAN 80	130	174	148.2	0	8.1	11.6	2	0.1	5	0	0	0	0	0
7 JAN 80	135	198	161	0	8.1	11.6	2	0.2	5	0	0	0	0	0
7 JAN 80	130	193	157	0	8.1	11.7	2	0.4	5	0	0	0	0	0
7 JAN 80	127	181	149.8	0	8.1	11.8	2.1	0.6	5	0	0	0	0	0
7 JAN 80	135	179	158.6	0	8.1	11.9	2.2	0.78	5	0	0	0	0	0
7 APR 80	127	189	152.8	0	7.5	10	11.3	0.19	5	0	0	0	0	0
7 APR 80	145	181	160.2	0	7.5	10	11.4	0.36	5	0	0	0	0	0
7 APR 80	132	184	160	0	7.5	10	11.4	0.77	5	0	0	0	0	20
7 APR 80	132	185	167.8	0	7.5	10	11.4	1.12	5	60	60	80	80	100
7 APR 80	163	193	173.4	0	7.5	9.9	11.1	1.49	5	80	100	100	100	100
19 MAY 80	137	159	145.6	0	7.2	7.6	19.1	0.16	5	0	0	0	0	0
19 MAY 80	136	165	149.4	0	7.2	7.5	19.1	0.28	5	0	0	0	0	0
19 MAY 80	133	160	142.4	0	7.2	7.6	19.1	0.63	5	20	40	40	40	40
19 MAY 80	133	151	141	0	7.1	7.3	19	0.97	5	100	100	100	100	100
19 MAY 80	127	167	142.6	0	7	7.3	19	1.29	5	100	100	100	100	100
9 JUN 80	74	93	87	0	7.3	8	21.2	0.14	10	0	0	0	0	10
9 JUN 80	68	113	82.7	0	7.2	8.1	21.3	0.26	10	0	0	0	0	0
9 JUN 80	70	96	80	0	7.2	8.1	21.4	0.52	9	0	0	11	11	11
9 JUN 80	70	98	86	0	7.2	7.9	22	0.72	10	80	100	100	100	100
9 JUN 80	67	92	83.7	0	7.2	8.7	24	0.93	9	100	100	100	100	100
7 JUL 80	110	182	143	0	7.4	7	25.9	0.1	5	0	0	0	0	40
7 JUL 80	117	157	137.2	0	7.4	7.3	26	0.22	5	0	0	0	0	0
7 JUL 80	117	150	135.6	0	7.4	7.6	26.1	0.62	5	0	0	0	0	20
7 JUL 80	140	160	152	0	7.4	7.7	26.1	0.83	5	0	0	20	40	80
7 JUL 80	127	169	147	0	7.2	7.9	25.8	1.09	5	80	80	80	100	100

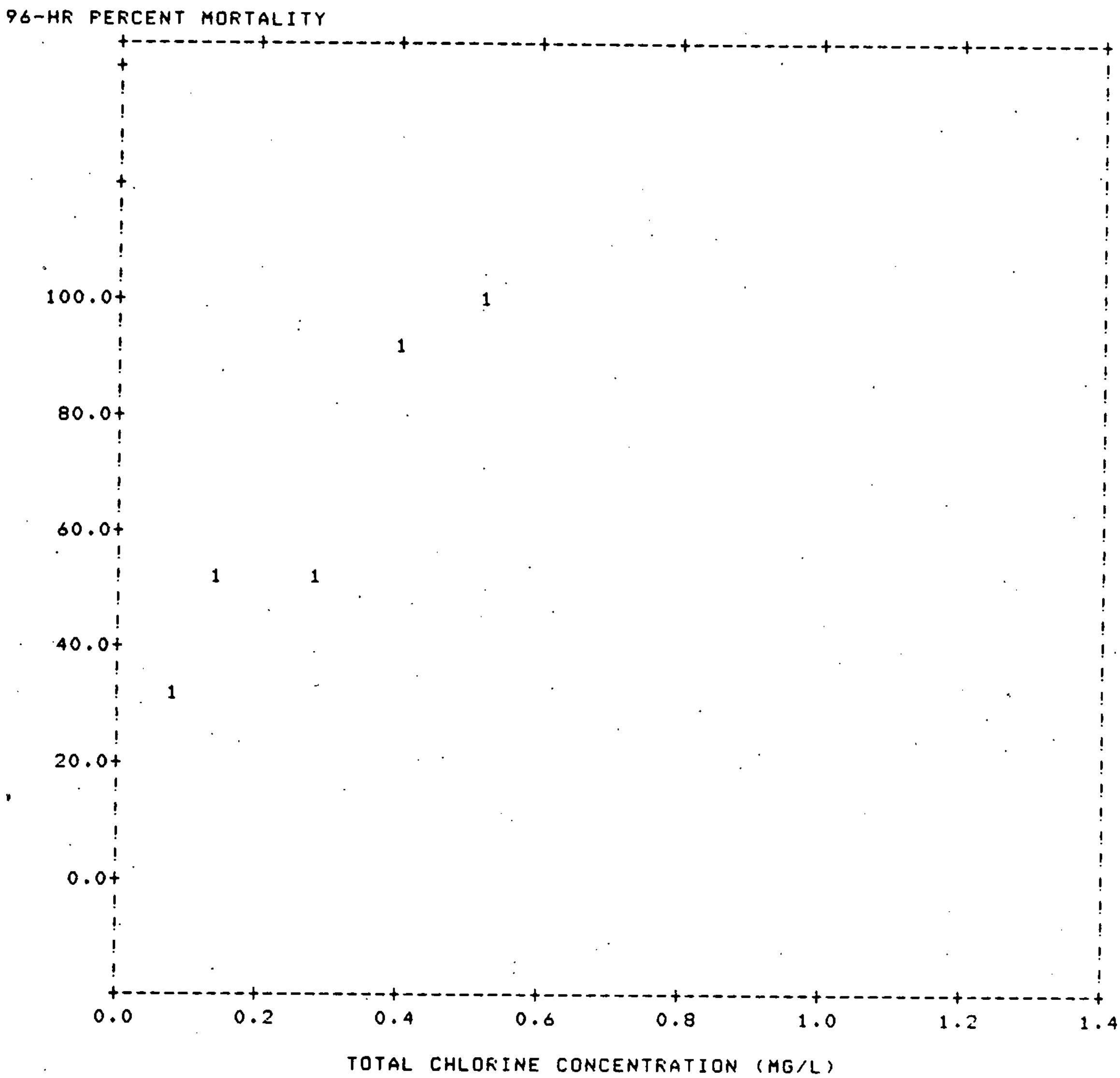


Figure 9. 96-hour percent mortality of the blueback herring, *Alosa aestivalis*, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 6 C.

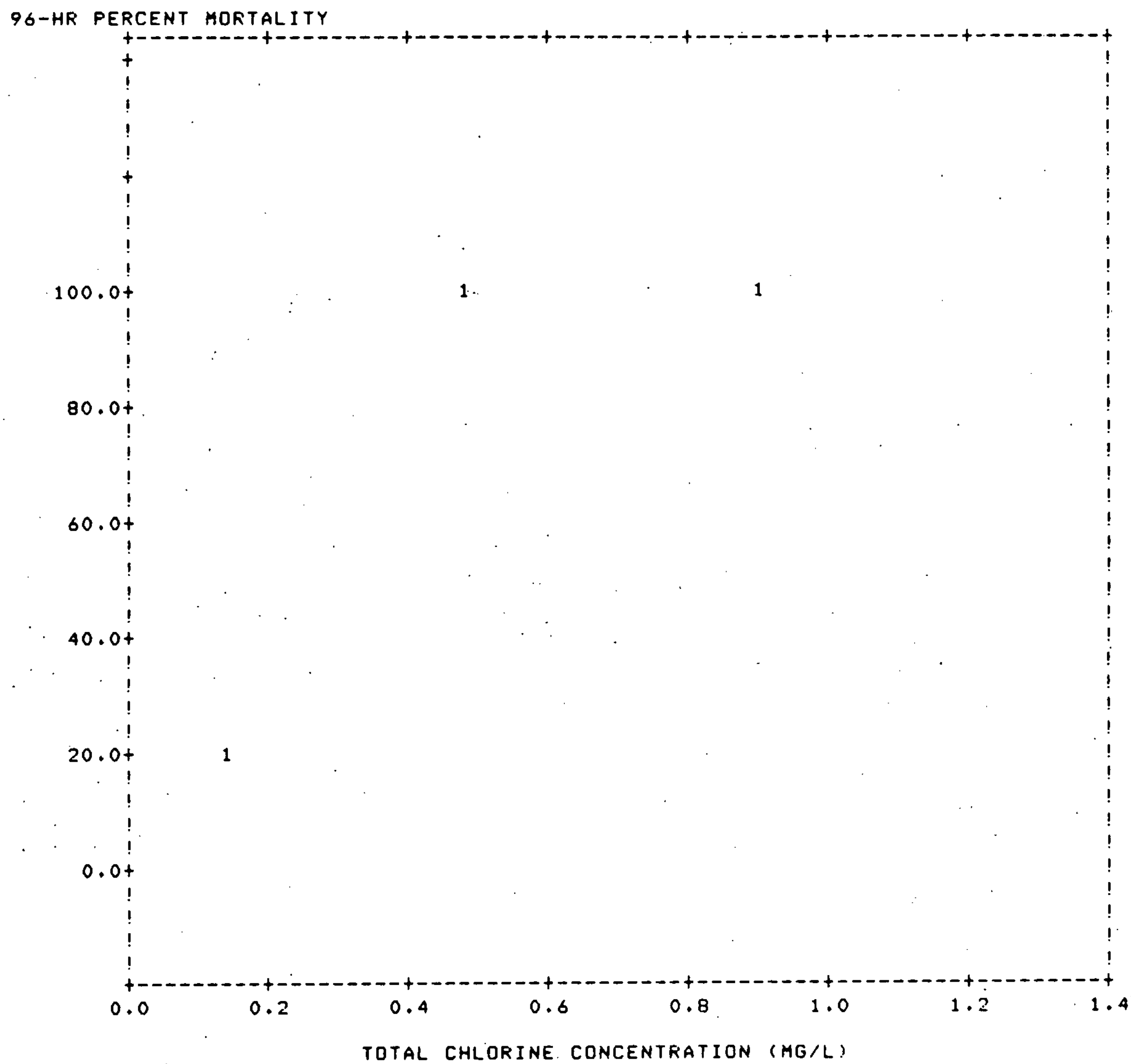


Figure 10. 96-hour percent mortality of the alewife, Alosa pseudoharengus, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. The 2-hour intermittent LC_{50} at 96 hours is about 0.27 mg/l total chlorine.

3. Test temperature was 22 C.

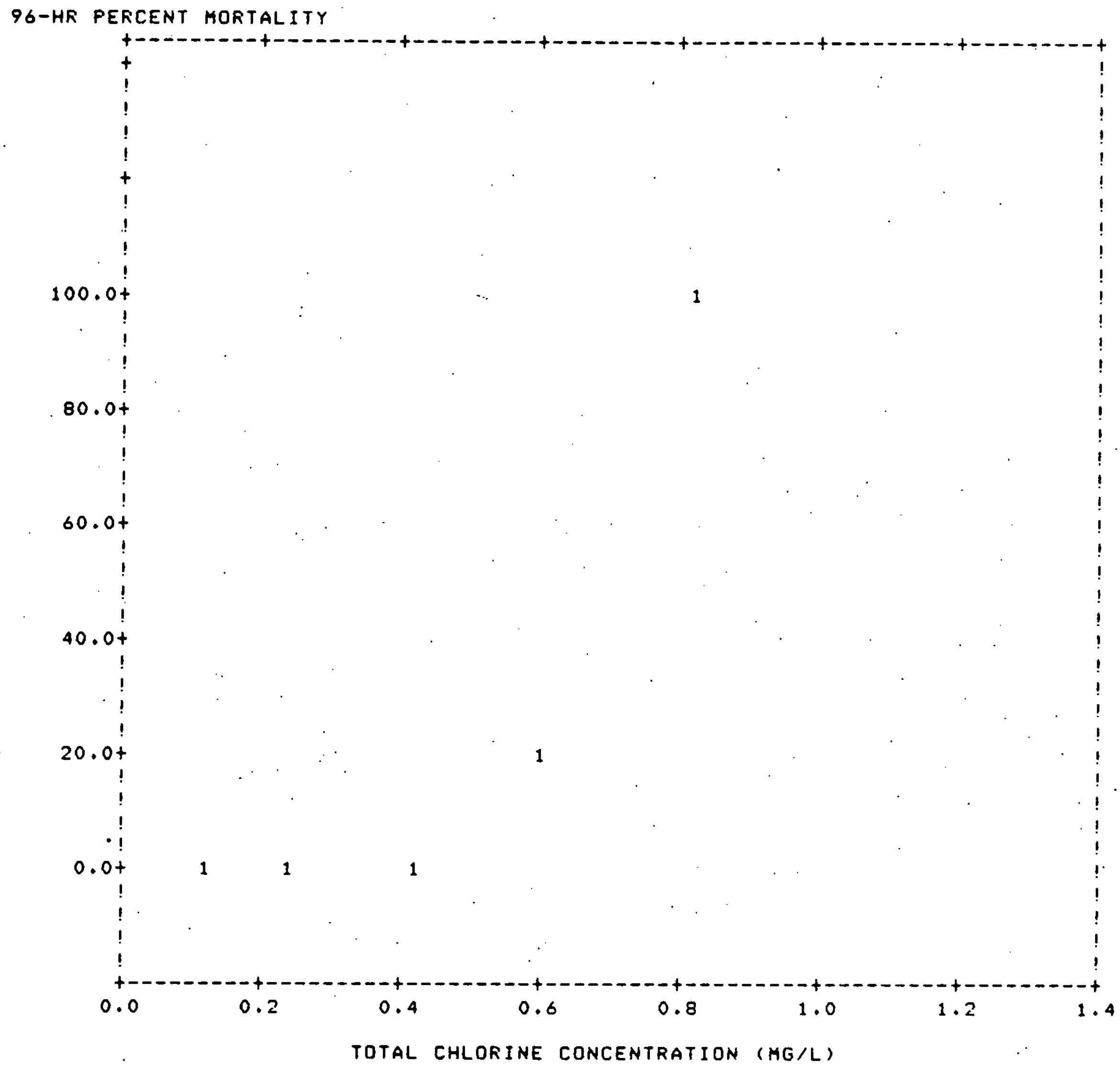


Figure 11. 96-hour percent mortality of the rainbow trout, <u>Salmo</u> <u>gairdneri</u>, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. The 2-hour intermittent LC_{50} at 96 hours is about 0.67 mg/l total chlorine.

3. Test temperature was 5 C.

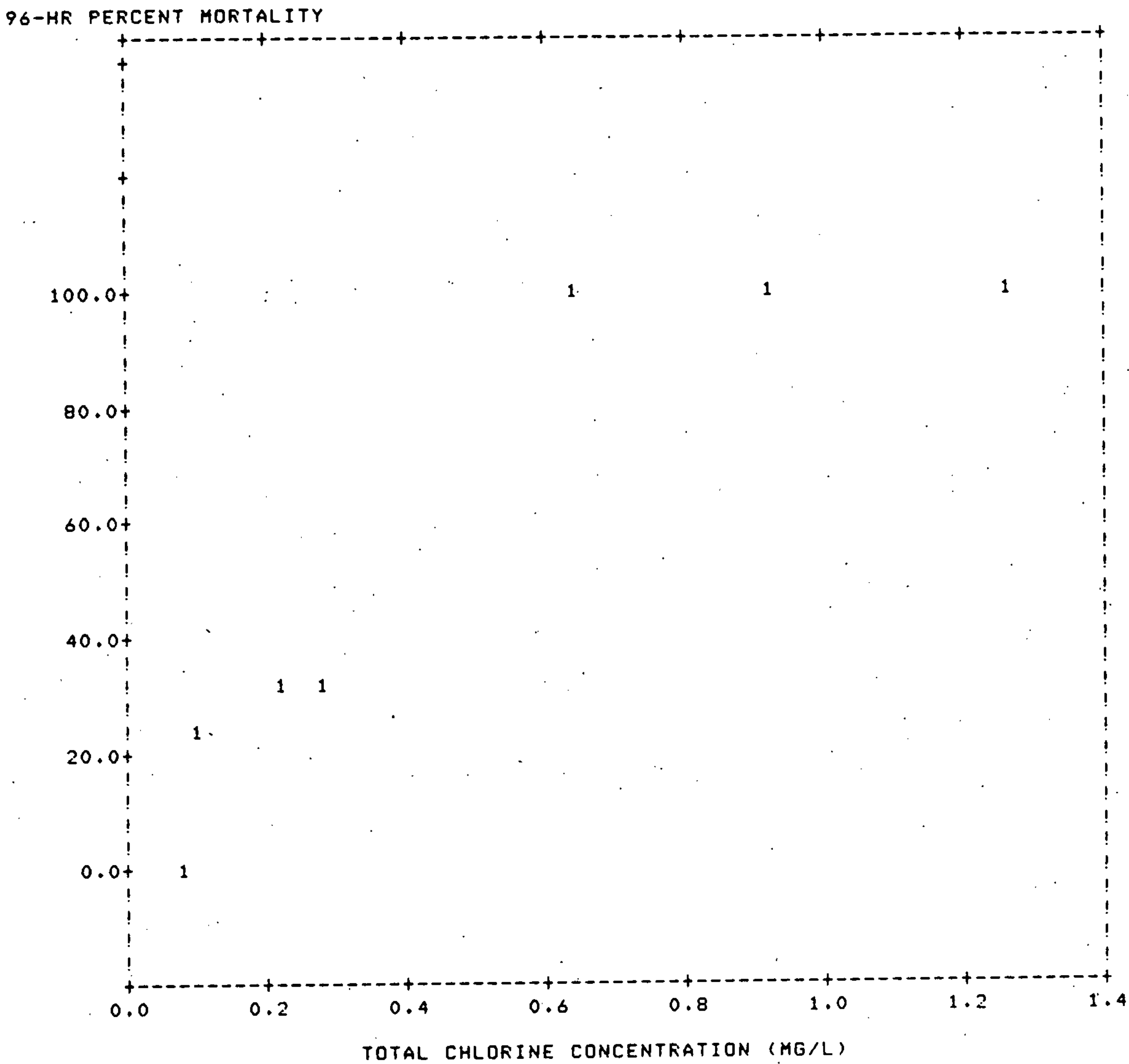


Figure 12. 96-hour percent mortality of the spottail shiner, *Notropis hudsonius*, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.35 mg/l total chlorine at 26 C.
3. Test temperatures were 6 C and 26 C.

White perch were tested at average temperatures between 2-26 C and at concentrations of total chlorine between 0.1-1.49 mg/l. Percent mortality at 96 hours at each respective test concentration of total chlorine is plotted for white perch at the respective test temperature in Figures 13-17. The $ILC_{50(96,2)}$ for white perch tested at 11, 19, 22, and 26 C was about 0.87, 0.69, 0.61, and 0.74 mg/l total chlorine, respectively. The mean $ILC_{50(96,2)}$ was 0.73 mg/l and the standard deviation was 0.11 mg/l. Although these results and those obtained at 2 C (no mortality at 0.78 mg/l total chlorine) indicate an inverse relationship between temperature and chlorine toxicity to white perch, no significant ($P \leq 0.05$) correlation ($r= -0.67$, d.f. 2) was found.

Ozone Toxicity

Bergen. Results of toxicity tests with ozone (measured as chlorine) at Bergen are given in Table 5. Cumulative mortalities over the 4-, 24-, 48-, 72-, and 96-hr periods are given in Table 6.

Ozone toxicity tests at Bergen with silvery minnow, spottail shiner, and white perch were conducted at a test temperature of 15.5 C and a salinity of 1.0 ppt. Mummichog and tidewater silverside were tested at 19 C and 0.5 ppt. Grass shrimp were tested under both these conditions. In a 48-hour test at 0.93 mg/l ozone (measured as chlorine) silvery minnow and spottail shiner experienced 50% and 100% mortality, respectively. However, 0.71 mg/l ozone (measured as chlorine) did not result in any mortality with silvery minnow and spottail shiner experienced only 20% mortality. In a 72-hour test at the highest test concentration , 1 mg/l ozone (measured as chlorine), tidewater silverside and grass shrimp experienced only 20% and 10% mortality, respectively. In a 96-hour test, white perch and grass shrimp experienced 0% and 20% mortality at 0.97 mg/l ozone (measured as chlorine; the highest concentration tested). Mummichog experienced no mortality at 1.0 mg/l ozone (measured as chlorine; the highest concentration tested) after 96 hours. Consequently, no $ILC_{50(96,2)}$ concentrations could be calculated because no test concentration of ozone resulted in more than 40% mortality in any 96-hour test. Percent mortality at 96 hours at each respective test concentration of ozone (measured as chlorine) is plotted for grass shrimp and mummichog in Figures 18 and 19, respectively.

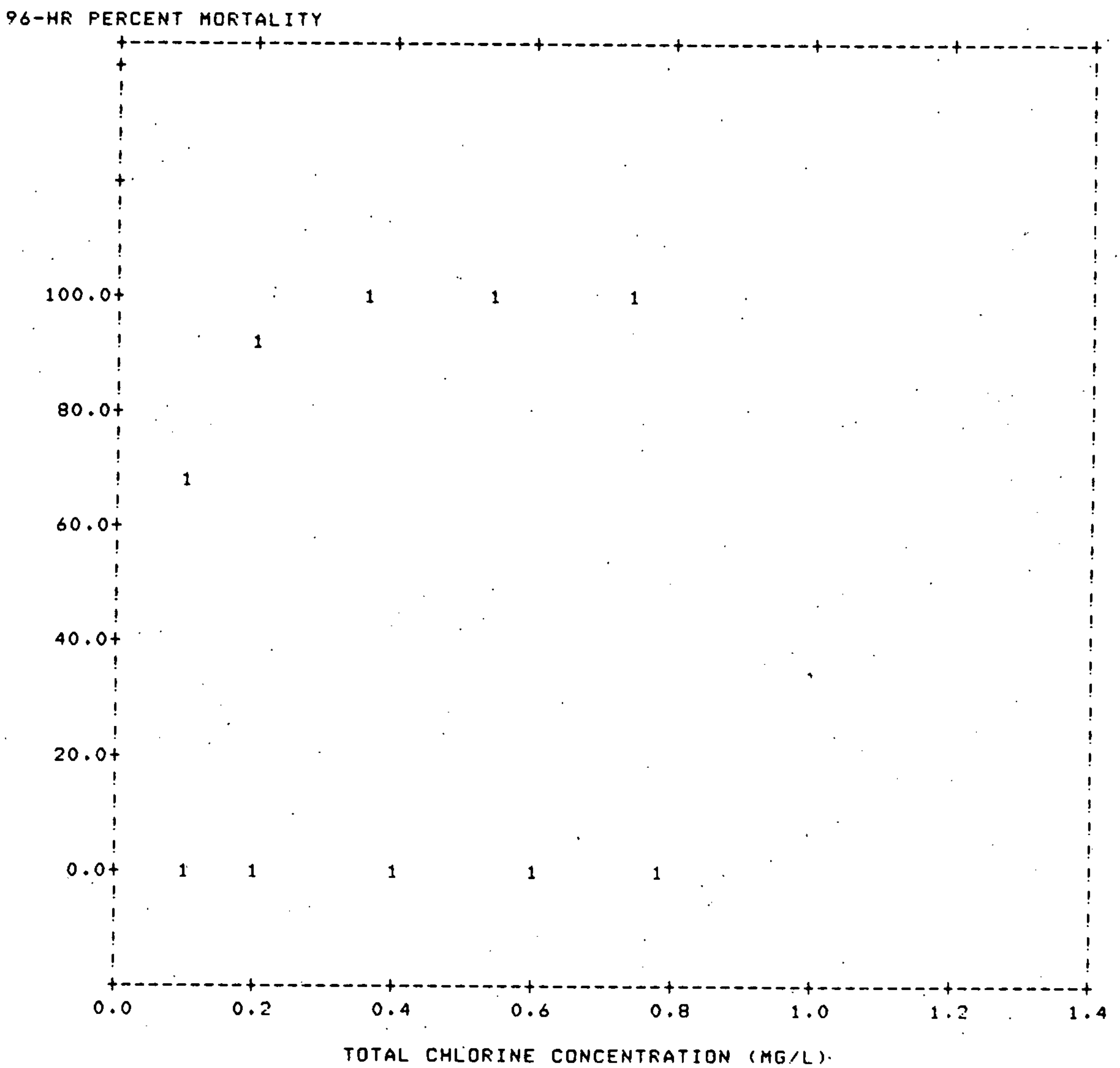


Figure 13. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 2 C.

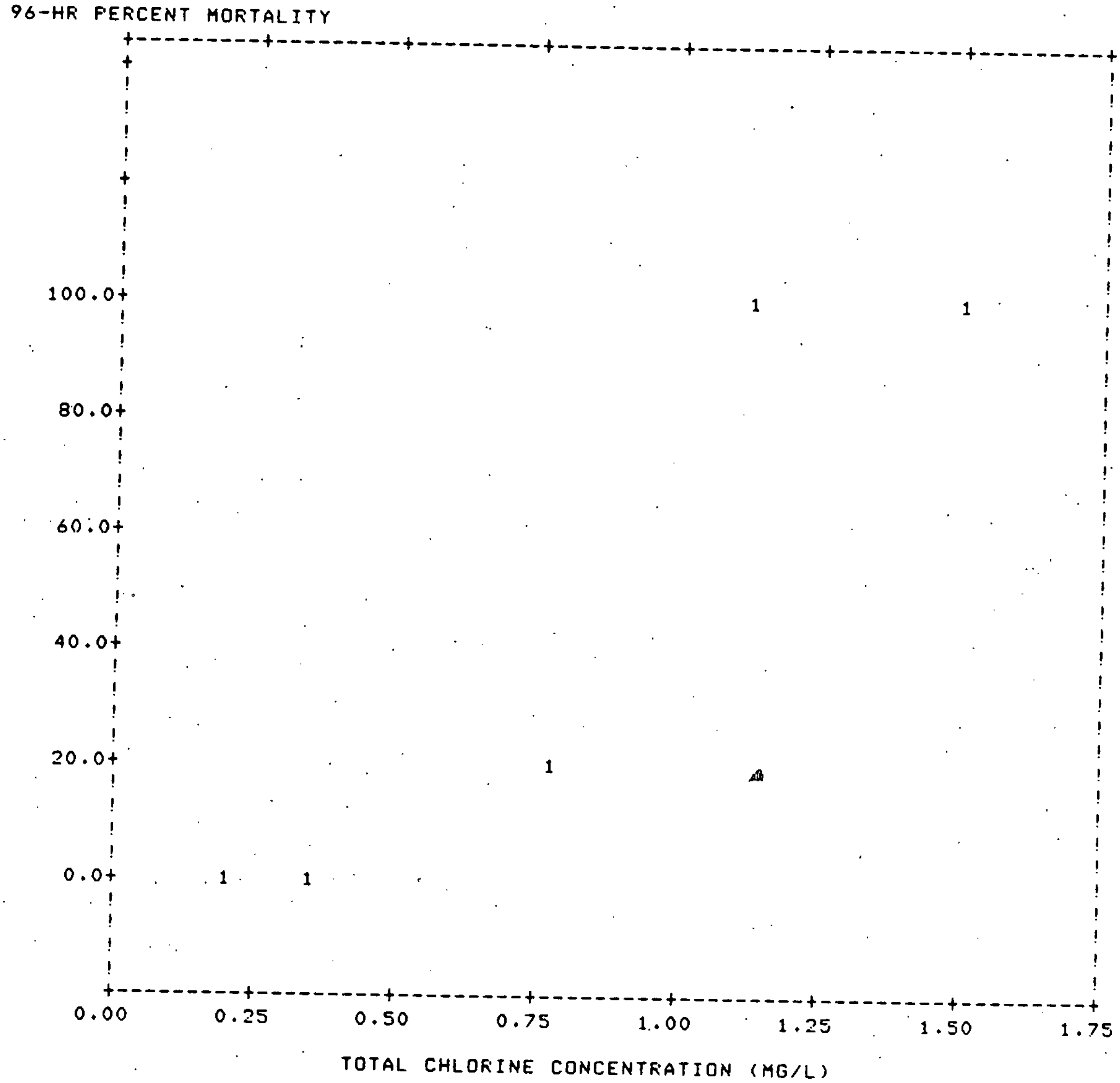


Figure 14. 96-hour percent mortality of the white perch, *Morone americana*, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.87 mg/l total chlorine.
3. Test temperature was 11 C.

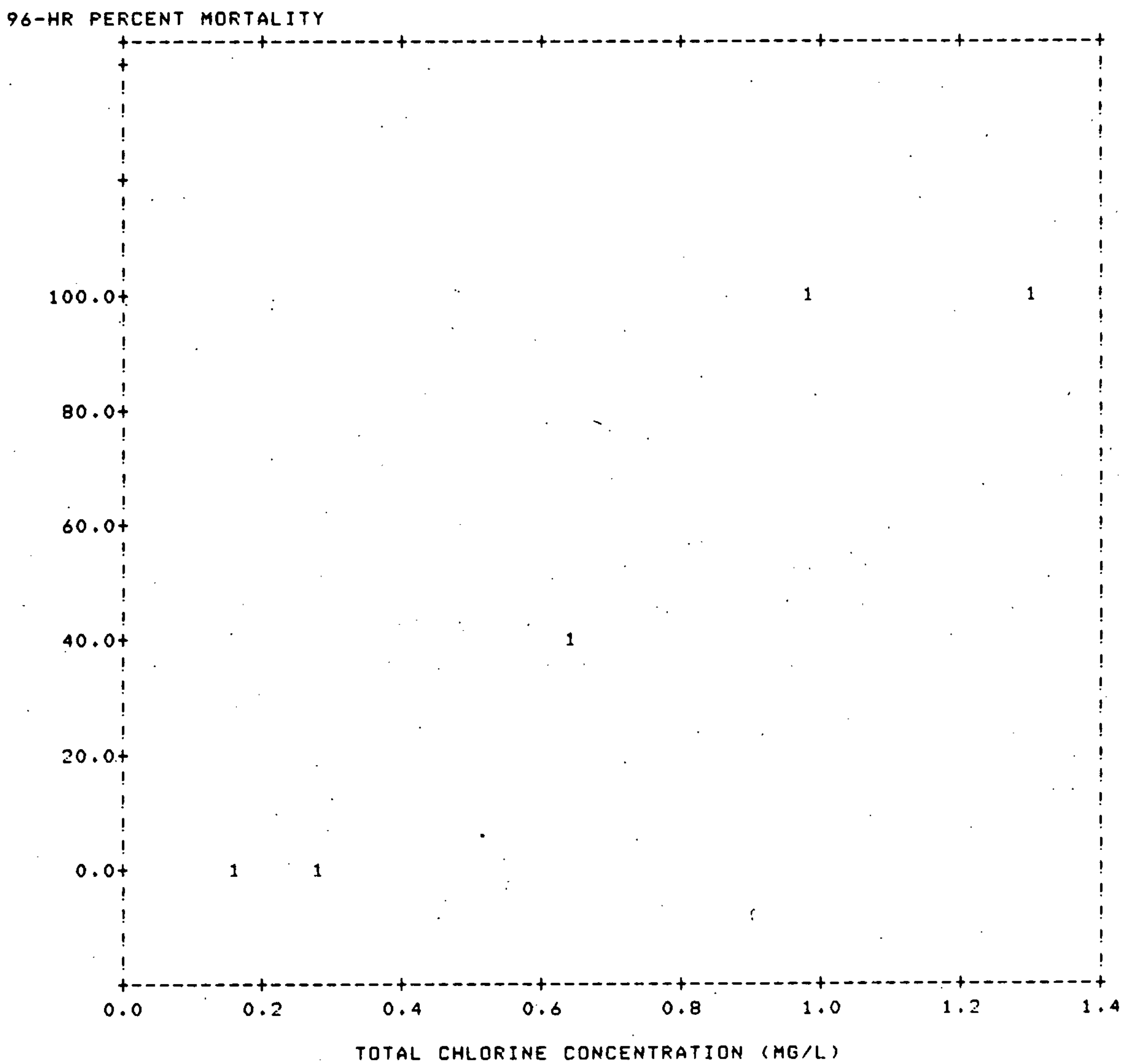


Figure 15. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.69 mg/l total chlorine.
3. Test temperature was 19 C.

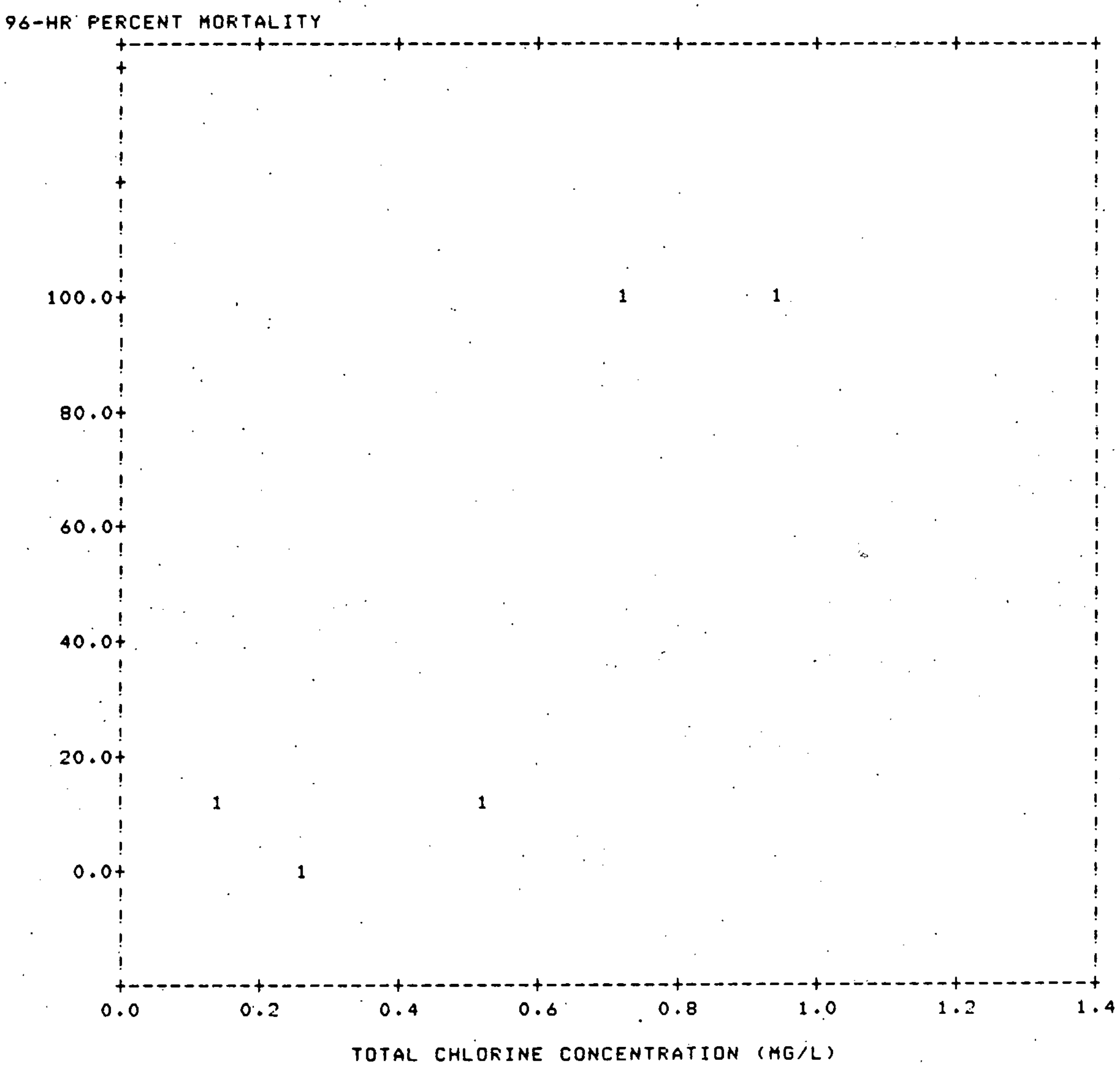


Figure 16. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. The 2-hour intermittent LC_{50} at 96 hours is about 0.61 mg/l total chlorine.

3. Test temperature was 22 C.

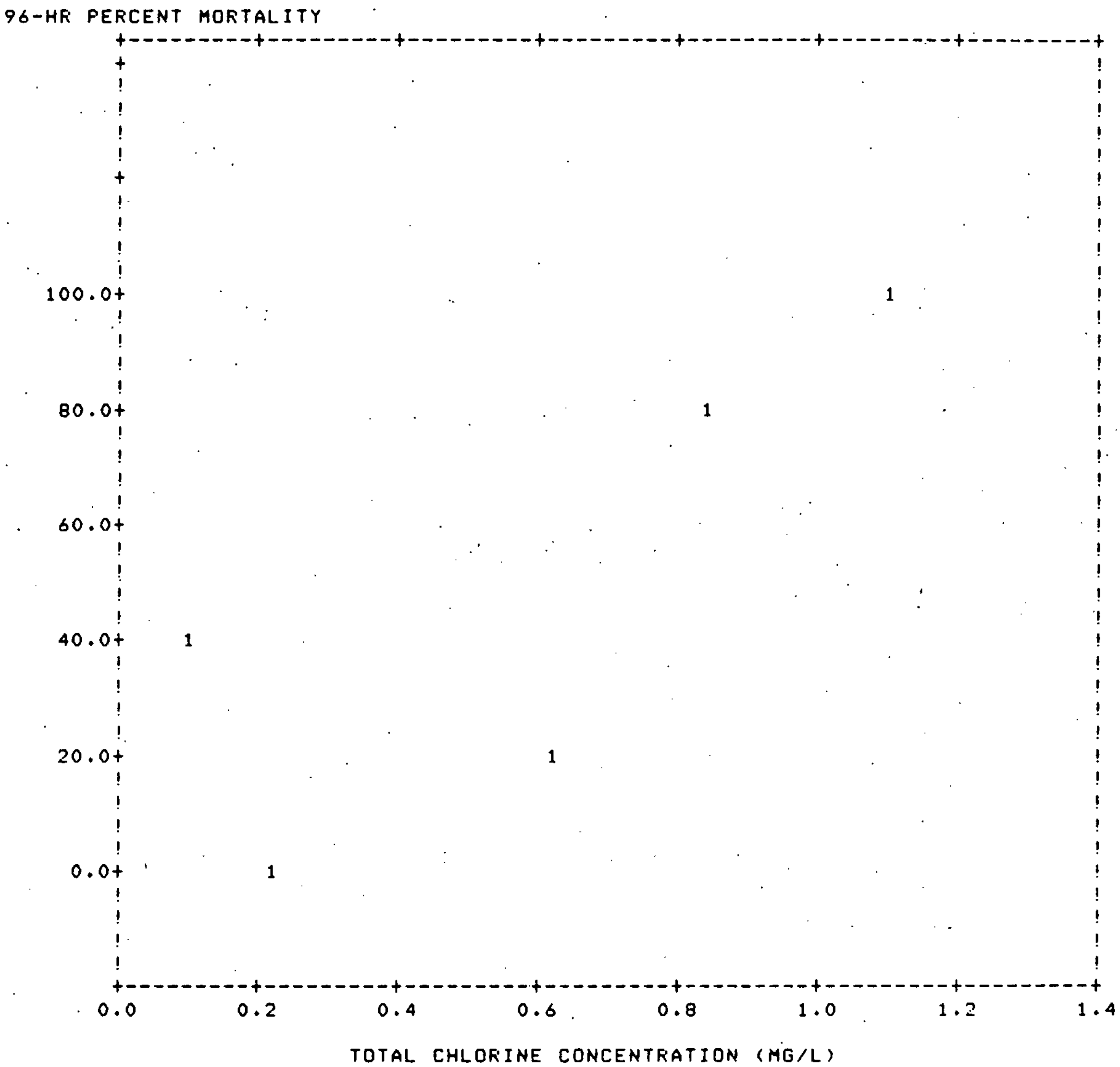


Figure 17. 96-hour percent mortality of the white perch, *Morone americana*, for two-hour daily exposures to total chlorine at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.74 mg/l total chlorine.
3. Test temperature was 26 C.

Table 5

Results of toxicity tests with ozone (measured as chlorine) for silvery minnow, Hybognathus nuchalis; spottail shiner, Notropis hudsonius; mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio; conducted at Bergen. (*=level of dissolved oxygen beyond 20 mg/l)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
HYBOGNATHUS NUCHALIS													
30 MAR 79	84.3	1	15.5	*	7.5	0.15	0	8	-	-	10	-	-
							48	8	0	0	10	0	0
30 MAR 79	88.7	1	15.5	*	7.5	0.39	0	8	-	-	9	-	-
							48	8	0	0	9	0	0
30 MAR 79	88.2	1	15.5	*	7.5	0.71	0	8	-	-	5	-	-
							48	8	0	0	5	0	0
30 MAR 79	89.4	1	15.5	*	7.5	0.93	0	8	-	-	8	-	-
							2	8	0	0	8	0	1
							2.5	8	0	0	7	1	2
							2.75	8	0	0	6	2	3
							3	8	0	0	4	4	4
							48	8	0	0	4	4	4
NOTROPIS HUDSONIUS													
30 MAR 79	106	1	15.5	*	7.5	0.39	0	2	-	-	1	-	-
							48	2	0	0	1	0	0
30 MAR 79	96.8	1	15.5	*	7.5	0.71	0	2	-	-	5	-	-
							2.5	2	0	0	4	1	1
							48	2	0	0	4	1	0
30 MAR 79	103	1	15.5	*	7.5	0.93	0	2	-	-	2	-	-
							2.5	2	0	0	1	1	1
							24	2	0	0	0	2	0
FUNDULUS HETEROCLITUS													
12 FEB 79	40.6	1	16	3.8	7.4	0.03	0	10	-	-	10	-	-
							4	10	0	0	10	0	0
							24	10	0	0	10	0	0
							48	6	4	6	5	5	5
							72	6	4	6	5	5	5
							90	6	4	6	5	5	5
12 FEB 79	38	1	16	3.8	7.4	0.03	0	10	-	-	8	-	-
							4	10	0	0	8	0	0
							24	10	0	0	8	0	0
							48	6	4	6	3	5	3
							72	6	4	6	3	5	3
							90	6	4	6	2	6	2
12 FEB 79	47.7	1	16	3.8	7.4	0.04	0	10	-	-	10	-	-
							4	10	0	0	10	0	8
							24	10	0	0	6	4	6
							48	6	4	6	6	4	6
							72	6	4	6	5	5	5
							90	6	4	6	4	6	4
12 FEB 79	40.2	1	16	3.8	7.4	0.07	0	10	-	-	10	-	-
							4	10	0	0	10	0	0
							24	10	0	0	5	5	5
							48	6	4	6	5	5	5
							72	6	4	6	3	7	3
							90	6	4	6	2	8	2
12 FEB 79	41	1	16	3.8	7.4	0.09	0	10	-	-	10	-	-
							4	10	0	0	10	0	0
							24	10	0	0	8	2	8
							48	6	4	6	7	3	7
							72	6	4	6	5	5	5
							90	6	4	6	4	6	4

Table 5 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
FUNDULUS HETEROCLITUS													
20 MAR 79	61.2	0.5	19	6.9	7.4	0.01	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
20 MAR 79	50.7	0.5	19	8.1	7.4	0.05	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
20 MAR 79	56.3	0.5	19	8	7.4	0.13	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
20 MAR 79	58.1	0.5	19	8	7.4	0.39	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
20 MAR 79	57.1	0.5	19	8	7.4	1	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
MENIDIA BERYLLINA													
20 MAR 79	46.8	0.5	19	8	7.4	0.09	0	5	-	-	5	-	-
							72	5	0	0	5	0	0
20 MAR 79	47	0.5	19	8	7.4	0.18	0	5	-	-	5	-	-
							44	5	0	0	4	1	0
							72	5	0	0	4	1	0
20 MAR 79	47.6	0.5	19	8	7.4	0.49	0	5	-	-	5	-	-
							72	5	0	0	5	0	0
20 MAR 79	41.8	0.5	19	8	7.4	1	0	5	-	-	5	-	-
							19.5	5	0	0	4	1	0
							72	5	0	0	4	1	0
MORONE AMERICANA													
28 MAR 79	182.8	1	15.5	8	7.5	0.97	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
PALAEMONETES PUGIO													
20 MAR 79	25.4	0.5	19	6	7.4	0.02	0	10	-	-	10	-	-
							22	10	0	0	9	1	0
							44	9	1	0	9	1	0
							72	9	1	0	9	1	0
20 MAR 79	24.1	0.5	19	8.8	7.4	0.09	0	10	-	-	10	-	-
							44	9	1	0	10	0	0
							72	9	1	0	10	0	0

Table 5 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
PALAEMONETES PUGIO													
20 MAR 79	25	0.5	19	8	7.4	0.18	0	10	-	-	10	-	-
							44	9	1	0	8	2	0
							72	9	1	0	8	2	0
20 MAR 79	27	0.5	19	8	7.4	0.49	0	10	-	-	10	-	-
							44	9	1	0	10	0	0
							72	9	1	0	10	0	0
20 MAR 79	24.1	0.5	19	8	7.4	1	0	10	-	-	10	-	-
							19.5	10	0	0	9	1	0
							44	9	1	0	9	1	0
							72	9	1	0	9	1	0
28 MAR 79	28.3	1	15.5	8	7.5	0.15	0	10	-	-	9	-	-
							65	10	0	0	7	2	0
							96	10	0	0	7	2	0
28 MAR 79	27.1	1	15.5	8	7.5	0.39	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
28 MAR 79	26.2	1	15.5	8	7.5	0.71	0	10	-	-	11	-	-
							96	10	0	0	11	0	0
28 MAR 79	21.6	1	15.5	8	7.5	0.97	0	10	-	-	10	-	-
							45	10	0	0	9	1	0
							48	10	0	0	8	2	1
							96	10	0	0	8	2	1

Table 6

Chronological summary of toxicity tests with ozone (measured as chlorine) for silvery minnow, Hybognathus nuchalis; spottail shiner, Notropis hudsonius; mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio; conducted at Bergen. (*=level of dissolved oxygen beyond 20 mg/l)

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	O3 CONC. (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
HYBOGNATHUS NUCHALIS														
30 MAR 79	62	100	84.3	1	7.5	*	15.5	0.15	10	0	0	0	-	-
30 MAR 79	75	106	88.7	1	7.5	*	15.5	0.39	9	0	0	0	-	-
30 MAR 79	82	92	88.2	1	7.5	*	15.5	0.71	5	0	0	0	-	-
30 MAR 79	79	112	89.4	1	7.5	*	15.5	0.93	8	50	50	50	-	-
NOTROPIS HUDSONIUS														
30 MAR 79	-	-	106	1	7.5	*	15.5	0.39	1	0	0	0	-	-
30 MAR 79	81	114	96.8	1	7.5	*	15.5	0.71	5	20	20	20	-	-
30 MAR 79	98	108	103	1	7.5	*	15.5	0.93	2	50	100	100	100	100
FUNDULUS HETEROCLITUS														
12 FEB 79	34	48	40.6	1	7.4	3.8	16	0.03	10	0	0	50	50	-
12 FEB 79	32	43	38	1	7.4	3.8	16	0.03	8	0	0	63	63	-
12 FEB 79	34	85	47.7	1	7.4	3.8	16	0.04	10	0	40	40	50	-
12 FEB 79	35	58	40.2	1	7.4	3.8	16	0.07	10	0	50	50	70	-
12 FEB 79	32	48	41	1	7.4	3.8	16	0.09	10	0	20	30	50	-
20 MAR 79	43	76	61.2	0.5	7.4	6.9	19	0.01	10	0	0	0	0	0
20 MAR 79	39	63	50.7	0.5	7.4	8.1	19	0.05	10	0	0	0	0	0
20 MAR 79	49	62	56.3	0.5	7.4	*	19	0.13	10	0	0	0	0	0
20 MAR 79	48	66	58.1	0.5	7.4	*	19	0.39	10	0	0	0	0	0
20 MAR 79	45	68	57.1	0.5	7.4	*	19	1	10	0	0	0	0	0
MENIDIA BERYLLINA														
20 MAR 79	40	52	46.8	0.5	7.4	*	19	0.09	5	0	0	0	0	-
20 MAR 79	43	56	47	0.5	7.4	*	19	0.18	5	0	0	20	20	-
20 MAR 79	43	51	47.6	0.5	7.4	*	19	0.49	5	0	0	0	0	-
20 MAR 79	37	46	41.8	0.5	7.4	*	19	1	5	0	20	20	20	-
MORONE AMERICANA														
28 MAR 79	173	197	182.8	1	7.5	*	15.5	0.97	5	0	0	0	0	0
PALAEMONETES PUGIO														
20 MAR 79	21	33	25.4	0.5	7.4	6	19	0.02	10	0	10	10	10	-
20 MAR 79	19	33	24.1	0.5	7.4	8.8	19	0.09	10	0	0	0	0	-
20 MAR 79	22	36	25	0.5	7.4	*	19	0.18	10	0	0	20	20	-
20 MAR 79	17	42	27	0.5	7.4	*	19	0.49	10	0	0	0	0	-
20 MAR 79	20	33	24.1	0.5	7.4	*	19	1	10	0	10	10	10	-
28 MAR 79	24	35	28.3	1	7.5	*	15.5	0.15	9	0	0	0	22	22
28 MAR 79	19	33	27.1	1	7.5	*	15.5	0.39	10	0	0	0	0	0
28 MAR 79	21	33	26.2	1	7.5	*	15.5	0.71	11	0	0	0	0	0
28 MAR 79	20	29	21.6	1	7.5	*	15.5	0.97	10	0	0	20	20	20

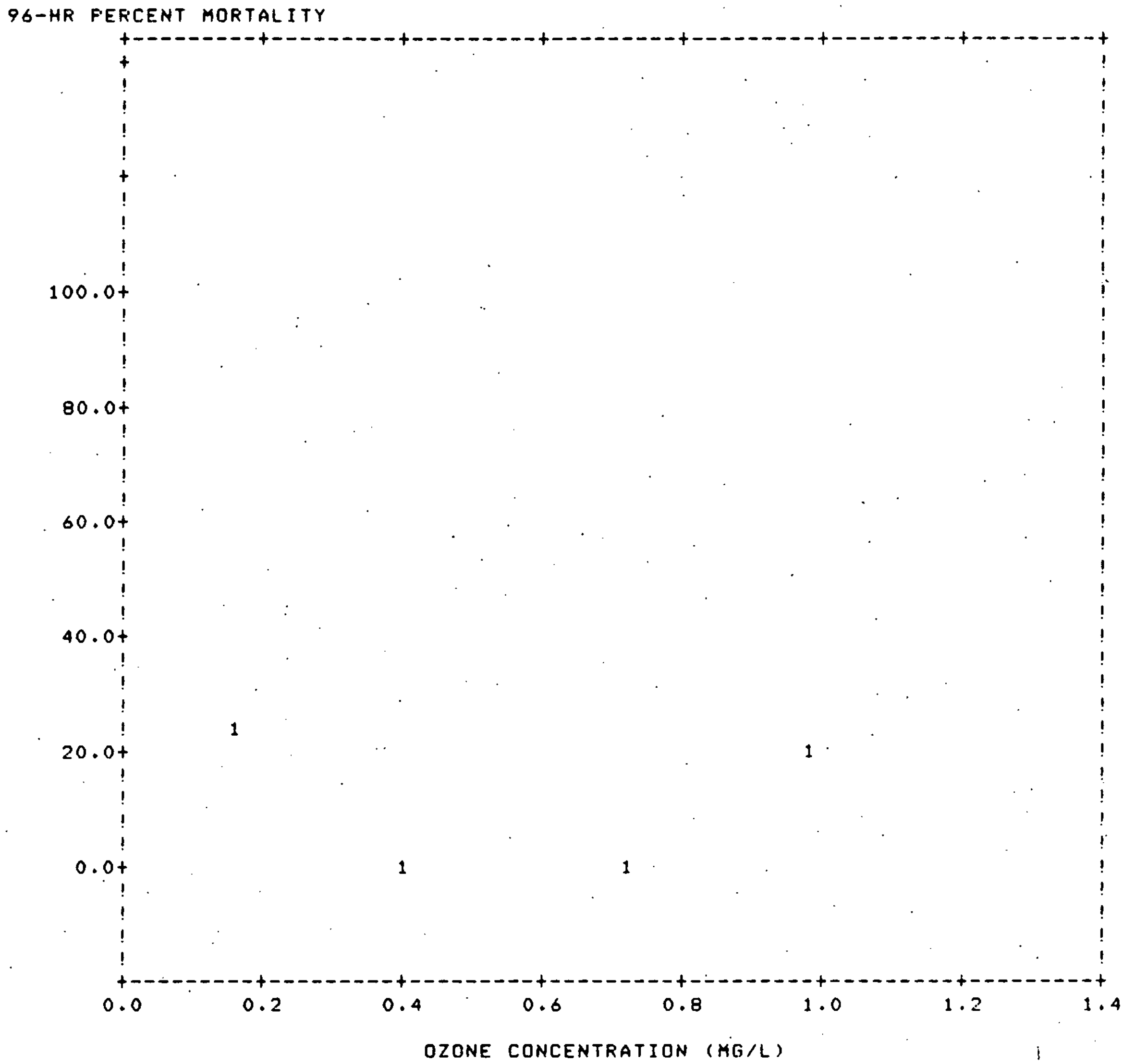


Figure 18. 96-hour percent mortality of the grass shrimp, Palaemonetes pugio, for two-hour daily exposures to ozone (measured as chlorine) at Bergen.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 19 C.

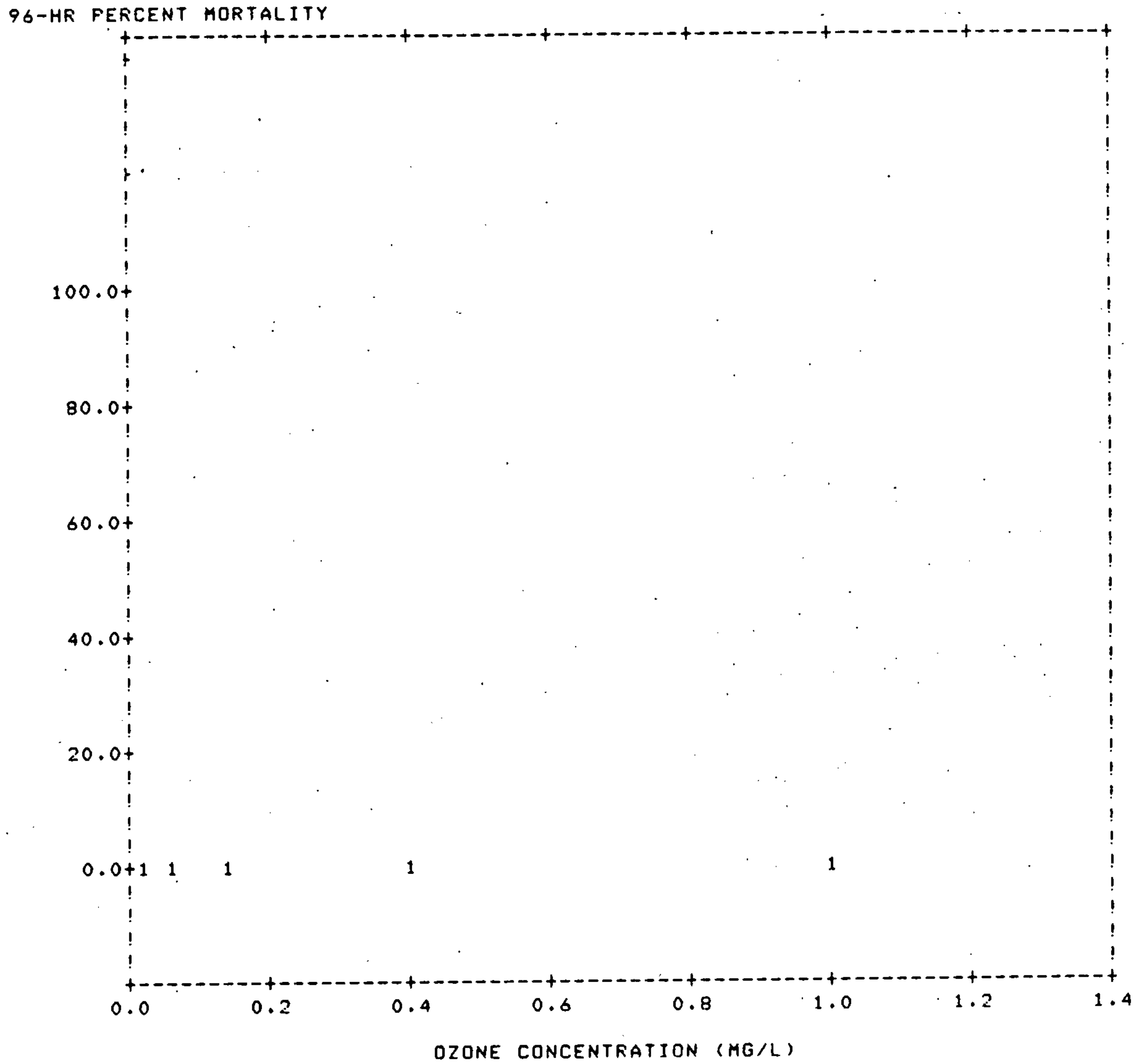


Figure 19. 96-hour percent mortality of the mummichog, Fundulus heteroclitus, for two-hour daily exposures to ozone (measured as chlorine) at Bergen.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 19 C.

Mercer. Results of toxicity tests with ozone (measured as chlorine) at Mercer are given in Table 7. Cumulative mortalities over the 4-, 24-, 48-, 72-, and 96-hr periods are given in Table 8. The test with blueback herring (Figure 20) and a test with white perch, conducted at an average temperature of about 2 C, were not evaluated because of unacceptable (greater than 20%) control mortality.

Alewife were tested at an average temperature of 22 C at ozone residuals (measured as chlorine) between 0.15-0.86 mg/l. Percent mortality at 96 hours at each respective test concentration of ozone (measured as chlorine) is plotted for alewife in Figure 21. Alewife experienced 100% mortality at all concentrations within 2 hours.

Rainbow trout were tested at an average temperature of about 5 C and at ozone residuals (measured as chlorine) between 0.11-0.94 mg/l. Percent mortality at 96 hours at each respective test concentration of ozone (measured as chlorine) is plotted for rainbow trout in Figure 22. The $ILC_{50(96,2)}$ for rainbow trout was 0.48 mg/l ozone (measured as chlorine).

Spottail shiner were tested at average temperatures of about 6 and 27 C and at ozone residuals (measured as chlorine) between 0.06-1.09 mg/l. Percent mortality at 96 hours at each respective test concentration is plotted for spottail shiner for 6 and 27 C in Figures 23 and 24, respectively. The $ILC_{50(96,2)}$ at 6 C (0.36 mg/l ozone) was slightly higher than the $ILC_{50(96,2)}$ at 27 C (0.26 mg/l ozone).

White perch were tested at average temperatures of about 2-27 C and at ozone residuals (measured as chlorine) between 0.06-1.44 mg/l. Percent mortality at 96 hours at each respective test concentration of ozone (measured as chlorine) is plotted for white perch at the respective test temperatures in Figures 25-29. The $ILC_{50(96,2)}$ for white perch tested at 11, 19, 21, and 27 C was about 0.55, 0.39, 0.32, and 0.43 mg/l ozone (measured as chlorine), respectively. The mean $ILC_{50(96,2)}$ was 0.42 mg/l ozone (measured as chlorine) and the standard deviation was 0.10. No significant ($P \leq 0.05$)

Table 7

Results of toxicity tests with ozone (measured as chlorine) for blueback herring, *Alosa aestivalis*; alewife, *Alosa pseudoharengus*; rainbow trout, *Salmo gairdneri*; spottail shiner, *Notropis hudsonius*; and white perch, *Morone americana*; conducted at Mercer. (*=level of dissolved oxygen beyond 20 mg/l)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
ALOSA AESTIVALIS													
11 DEC 79	68.9	0	6.3	11.5	7.7	0.08	0	10	-	-	10	-	-
							19.5	9	1	1	10	0	1
							23	8	2	0	9	1	2
							23.75	8	2	0	7	3	0
							49	7	3	0	6	4	0
							96	2	8	0	5	5	0
11 DEC 79	75.9	0	6.3	12.6	7.7	0.28	0	10	-	-	10	-	-
							1.5	10	0	0	10	0	1
							2	10	0	0	9	1	0
							3.5	10	0	0	9	1	1
							4	10	0	0	8	2	1
							19.5	9	1	1	0	10	0
11 DEC 79	69.7	0	6.8	13.3	7.8	0.47	0	10	-	-	10	-	-
							1	10	0	0	10	0	4
							1.5	10	0	0	7	3	4
							1.83	10	0	0	6	4	4
							2	10	0	0	3	7	1
							4.5	10	0	0	0	10	0
11 DEC 79	72.6	0	6.8	13.8	7.8	0.75	0	10	-	-	10	-	-
							0.25	10	0	0	10	0	1
							1.17	10	0	0	9	1	8
							1.5	10	0	0	4	6	4
							1.75	10	0	0	3	7	3
							1.91	10	0	0	0	10	0
11 DEC 79	73.8	0	6.8	14.5	7.8	1.19	0	10	-	-	10	-	-
							0.5	10	0	0	10	0	1
							1	10	0	0	9	1	8
							1.17	10	0	0	3	7	2
							1.5	10	0	0	2	8	2
							1.67	10	0	0	0	10	0
ALOSA PSEUDOHARENGUS													
9 JUN 80	28.3	0	22	14	7.6	0.15	0	10	-	-	10	-	-
							1.25	10	0	0	8	2	1
							1.5	10	0	0	6	4	6
							1.75	10	0	0	2	8	2
							1.91	10	0	0	1	9	1
							2	10	0	0	0	10	0
9 JUN 80	27.2	0	22	16.2	7.6	0.27	0	10	-	-	10	-	-
							0.67	10	0	0	10	0	5
							1	10	0	0	7	3	5
							1.25	10	0	0	4	6	4
							1.33	10	0	0	1	9	1
							1.75	10	0	0	0	10	0
9 JUN 80	28	0	22	18.2	7.6	0.48	0	10	-	-	10	-	-
							0.5	10	0	0	10	0	1
							0.67	10	0	0	6	4	6
							0.75	10	0	0	2	8	2
							1.08	10	0	0	0	10	0
9 JUN 80	28.7	0	22	*	7.6	0.86	0	10	-	-	10	-	-
							0.5	10	0	0	5	5	5
							0.58	10	0	0	2	8	2
							0.67	10	0	0	0	10	0

Table 7 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
SALMO GAIRDNERI													
24 MAR 80	160.6	0	5.2	12.6	7.9	0.11	0	4	-	-	5	-	-
							96	4	0	0	5	0	0
24 MAR 80	157.8	0	5.2	13.2	7.9	0.21	0	4	-	-	5	-	-
							96	4	0	0	5	0	0
24 MAR 80	162.6	0	5.2	13.7	7.9	0.35	0	4	-	-	5	-	-
							96	4	0	0	5	0	0
24 MAR 80	149.8	0	5.2	14.2	7.9	0.62	0	4	-	-	5	-	-
							30	4	0	0	4	1	1
							43	4	0	0	3	2	0
							68	4	0	0	2	3	0
							72.5	4	0	0	1	4	0
							91.5	4	0	0	0	5	0
24 MAR 80	170.8	0	5.2	15.4	7.9	0.94	0	4	-	-	5	-	-
							2	4	0	0	5	0	2
							6.5	4	0	0	3	2	0
							27	4	0	0	3	2	1
							48	4	0	0	1	4	0
							51.5	4	0	0	0	5	0
NOTROPIS HUDSONIUS													
11 DEC 79	73.5	0	6.3	11.5	7.7	0.08	0	2	-	-	2	-	-
							96	2	0	0	2	0	0
11 DEC 79	77.3	0	6.3	12.1	7.6	0.45	0	2	-	-	3	-	-
							67.5	2	0	0	1	2	0
							96	2	0	0	1	2	0
11 DEC 79	73.3	0	6.4	12.5	7.6	1.09	0	2	-	-	3	-	-
							19.5	2	0	0	2	1	0
							23.75	2	0	0	2	1	1
							25.5	2	0	0	1	2	0
							67.5	2	0	0	0	3	0
8 JUL 80	36.5	0	26.8	10.6	7.4	0.06	0	10	-	-	10	-	-
							20	10	0	0	9	1	0
							96	10	0	0	9	1	0
8 JUL 80	36.9	0	26.8	11.4	7.4	0.15	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
8 JUL 80	31.9	0	26.8	12.3	7.4	0.3	0	10	-	-	10	-	-
							0.67	10	0	0	9	1	0
							1.67	10	0	0	6	4	2
							2	10	0	0	4	6	1
							20	10	0	0	1	9	0
							96	10	0	0	1	9	0
8 JUL 80	35.8	0	28	18	7.3	0.56	0	10	-	-	10	-	-
							0.25	10	0	0	8	2	3
							0.41	10	0	0	5	5	1
							0.58	10	0	0	3	7	0
							0.91	10	0	0	2	8	0
							2	10	0	0	0	10	0

Table 7 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	CONTROL NO. DEAD	CONTROL NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	EXPERIMENTAL NO. DEAD	EXPERIMENTAL NO. WITH L.O.E.
MORONE AMERICANA													
17 DEC 79	67.9	0	1.8	12.9	7.9	0.11	0	10	-	-	10	-	-
							20	8	2	0	10	0	0
							45	6	4	0	9	1	1
							67.5	6	4	2	5	5	2
							75	5	5	4	4	6	2
							92.5	1	9	1	0	10	0
17 DEC 79	64.4	0	1.8	13.2	7.9	0.23	0	10	-	-	10	-	-
							20	8	2	0	9	1	0
							45	6	4	0	6	4	2
							47.5	6	4	0	5	5	1
							67.5	6	4	2	1	9	0
							92.5	1	9	1	0	10	0
17 DEC 79	67.4	0	2.3	13	7.9	0.47	0	10	-	-	10	-	-
							20	8	2	0	4	6	1
							26.5	8	2	0	4	6	2
							27	8	2	0	3	7	1
							28.5	8	2	0	3	7	2
							45	6	4	0	0	10	0
17 DEC 79	65.8	0	2.8	13.1	7.8	0.76	0	10	-	-	10	-	-
							20	8	2	0	1	9	1
							23.5	8	2	0	0	10	0
17 DEC 79	61.7	0	2.8	13.4	7.8	1.18	0	10	-	-	10	-	-
							2	10	0	0	10	0	1
							3	10	0	0	9	1	0
							4.5	10	0	0	9	1	3
							20	8	2	0	0	10	0
7 JAN 80	139.4	0	2	12.3	8.1	0.11	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
MORONE AMERICANA													
8 APR 80	184.8	0	11	14.8	7.5	1.22	0	5	-	-	5	-	-
							22	5	0	0	5	0	1
							26.25	5	0	0	4	1	3
							27.5	5	0	0	4	1	4
							28	5	0	0	2	3	2
							29	5	0	0	0	5	0
8 APR 80	177.6	0	11.4	14.7	7.5	1.44	0	5	-	-	5	-	-
							1	5	0	0	5	0	2
							2.75	5	0	0	3	2	1
							3.75	5	0	0	2	3	0
							26.75	5	0	0	1	4	0
							51.5	5	0	0	0	5	0
19 MAY 80	148.6	0	19	9.1	7.2	0.13	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
19 MAY 80	151.6	0	19	9.7	7.2	0.28	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
19 MAY 80	144.2	0	19	10.3	7.2	0.46	0	5	-	-	5	-	-
							20	5	0	0	5	0	1
							24	5	0	0	4	1	0
							68	5	0	0	2	3	0
							92	5	0	0	1	4	0
							96	5	0	0	1	4	0
19 MAY 80	156	0	18.8	11.4	7.2	0.7	0	5	-	-	5	-	-
							2.25	5	0	0	4	1	0
							3.25	5	0	0	3	2	0
							22	5	0	0	2	3	0
							27	5	0	0	1	4	0
							74	5	0	0	0	5	0

Table 7 (continued)

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	O3 CONC. (MG/L)	TIME(HRS.) FROM START OF TEST	CONTROL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
MORONE AMERICANA													
19 MAY 80	148.8	0	19	13.1	7.2	1	0	5	-	-	5	-	-
							2.5	5	0	0	5	0	1
							3	5	0	0	4	1	0
							20	5	0	0	2	3	0
							27	5	0	0	1	4	1
							27.75	5	0	0	0	5	0
9 JUN 80	79.7	0	20.6	10.7	7.3	0.15	0	7	-	-	7	-	-
							65	7	0	0	6	1	0
							89	6	1	0	6	1	0
							96	6	1	1	6	1	0
9 JUN 80	92	0	20.6	11.7	7.3	0.27	0	7	-	-	7	-	-
							65	7	0	0	6	1	0
							89	6	1	0	6	1	0
							94	6	1	0	5	2	1
							94.5	6	1	0	4	3	0
							96	6	1	1	4	3	0
9 JUN 80	84.1	0	20.6	12.4	7.3	0.49	0	7	-	-	7	-	-
							3	7	0	0	6	1	0
							18	7	0	0	4	3	0
							47.5	7	0	0	3	4	0
							89	6	1	0	3	4	0
							96	6	1	1	2	5	0
9 JUN 80	82.3	0	21	13.7	7.3	0.86	0	7	-	-	7	-	-
							0.75	7	0	0	6	1	0
							2	7	0	0	5	2	1
							2.25	7	0	0	4	3	0
							3.5	7	0	0	3	4	0
							18	7	0	0	0	7	0
8 JUL 80	122.4	0	26.8	10.6	7.4	0.06	0	5	-	-	5	-	-
							94	4	1	0	5	0	0
							96	4	1	0	5	0	0
8 JUL 80	127	0	26.8	11.4	7.4	0.15	0	5	-	-	5	-	-
							49.5	5	0	0	5	0	1
							50.25	5	0	0	4	1	0
							94	4	1	0	3	2	0
							96	4	1	0	3	2	0
8 JUL 80	127.6	0	26.8	12.3	7.4	0.3	0	5	-	-	5	-	-
							94	4	1	0	5	0	0
							96	4	1	0	5	0	0
8 JUL 80	125.4	0	26.3	13.1	7.4	0.56	0	5	-	-	5	-	-
							3	5	0	0	5	0	1
							4	5	0	0	4	1	0
							20	5	0	0	2	3	0
							25.5	5	0	0	1	4	0
							44	5	0	0	0	5	0

Table 8

Chronological summary of toxicity tests with ozone (measured as chlorine) for blueback herring, <u>Alosa aestivalis</u>; alewife, <u>Alosa pseudoharengus</u>; rainbow trout, <u>Salmo gairdneri</u>; spottail shiner, <u>Notropis hudsonius</u>; and white perch, <u>Morone americana</u>; conducted at Mercer. (*=level of dissolved oxygen beyond 20 mg/l)

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	O3 CONC. (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
ALOSA AESTIVALIS														
11 DEC 79	54	77	68.9	0	7.7	11.5	6.3	0.08	10	0	30	30	40	50
11 DEC 79	68	84	75.9	0	7.7	12.6	6.3	0.28	10	20	100	100	100	100
11 DEC 79	55	84	69.7	0	7.8	13.3	6.8	0.47	10	70	100	100	100	100
11 DEC 79	61	85	72.6	0	7.8	13.8	6.8	0.75	10	100	100	100	100	100
11 DEC 79	65	78	73.8	0	7.8	14.5	6.8	1.19	10	100	100	100	100	100
ALOSA PSEUDOHARENGUS														
9 JUN 80	24	32	28.3	0	7.6	14	22	0.15	10	100	100	100	100	100
9 JUN 80	24	30	27.2	0	7.6	16.2	22	0.27	10	100	100	100	100	100
9 JUN 80	23	32	28	0	7.6	18.2	22	0.48	10	100	100	100	100	100
9 JUN 80	25	33	28.7	0	7.6	*	22	0.86	10	100	100	100	100	100
SALMO GAIRDNERI														
24 MAR 80	147	180	160.6	0	7.9	12.6	5.2	0.11	5	0	0	0	0	0
24 MAR 80	138	180	157.8	0	7.9	13.2	5.2	0.21	5	0	0	0	0	0
24 MAR 80	153	173	162.6	0	7.9	13.7	5.2	0.35	5	0	0	0	0	0
24 MAR 80	140	158	149.8	0	7.9	14.2	5.2	0.62	5	0	0	40	60	100
24 MAR 80	152	186	170.8	0	7.9	15.4	5.2	0.94	5	0	40	80	100	100
NOTROPIS HUDSONIUS														
11 DEC 79	63	84	73.5	0	7.7	11.5	6.3	0.08	2	0	0	0	0	0
11 DEC 79	69	82	77.3	0	7.6	12.1	6.3	0.45	3	0	0	0	67	67
11 DEC 79	53	100	73.3	0	7.6	12.5	6.4	1.09	3	0	33	67	100	100
8 JUL 80	32	43	36.5	0	7.4	10.6	26.8	0.06	10	0	10	10	10	10
8 JUL 80	29	48	36.9	0	7.4	11.4	26.8	0.15	10	0	0	0	0	0
8 JUL 80	28	37	31.9	0	7.4	12.3	26.8	0.3	10	60	90	90	90	90
8 JUL 80	28	40	35.8	0	7.3	18	28	0.56	10	100	100	100	100	100
MORONE AMERICANA														
17 DEC 79	58	79	67.9	0	7.9	12.9	1.8	0.11	10	0	0	10	50	100
17 DEC 79	55	74	66.4	0	7.9	13.2	1.8	0.23	10	0	10	50	90	100
17 DEC 79	60	79	67.4	0	7.9	13	2.3	0.47	10	0	60	100	100	100
17 DEC 79	53	75	65.8	0	7.8	13.1	2.8	0.76	10	0	100	100	100	100
17 DEC 79	56	75	61.7	0	7.8	13.4	2.8	1.18	10	10	100	100	100	100
7 JAN 80	97	183	139.4	0	8.1	12.3	2	0.11	5	0	0	0	0	0
7 JAN 80	105	206	154.2	0	8.1	12.6	2	0.26	5	0	0	20	20	20
7 JAN 80	115	190	142.2	0	8.1	13	2	0.54	5	0	0	0	20	20
7 JAN 80	103	195	145.6	0	8.1	13.4	2	0.76	5	0	0	0	0	0
7 JAN 80	128	197	150	0	8.1	13.9	2	1.14	5	0	0	0	0	40

Table 8 (continued)

DATE	TOTAL LENGTH (MM) MIN.	MAX.	MEAN	SALINITY (PPT)	PH	D.O. (MG/L)	TEMP. (C)	O3 CONC. (MG/L)	NO.EXP. ORG.	4 HOUR % MORT.	24 HOUR % MORT.	48 HOUR % MORT.	72 HOUR % MORT.	96 HOUR % MORT.
MORONE AMERICANA														
8 APR 80	157	201	176.2	0	7.5	11.9	11.4	0.28	5	0	0	0	0	0
8 APR 80	174	190	181.6	0	7.5	12.6	11.4	0.6	5	0	0	20	40	60
8 APR 80	175	189	181	0	7.5	13.3	11.4	0.85	5	0	20	40	60	80
8 APR 80	171	207	184.8	0	7.5	14.8	11	1.22	5	0	0	100	100	100
8 APR 80	155	192	177.6	0	7.5	14.7	11.4	1.44	5	60	60	80	100	100
19 MAY 80	135	162	148.6	0	7.2	9.1	19	0.13	5	0	0	0	0	0
19 MAY 80	135	178	151.6	0	7.2	9.7	19	0.28	5	0	0	0	0	0
19 MAY 80	127	153	144.2	0	7.2	10.3	19	0.46	5	0	20	20	60	80
19 MAY 80	142	185	156	0	7.2	11.4	18.8	0.7	5	40	60	80	80	100
19 MAY 80	132	165	148.8	0	7.2	13.1	19	1	5	20	60	100	100	100
9 JUN 80	59	98	79.7	0	7.3	10.7	20.6	0.15	7	0	0	0	14	14
9 JUN 80	71	110	92	0	7.3	11.7	20.6	0.27	7	0	0	0	14	43
9 JUN 80	63	111	84.1	0	7.3	12.4	20.6	0.49	7	14	43	57	57	71
9 JUN 80	73	95	82.3	0	7.3	13.7	21	0.86	7	57	100	100	100	100
8 JUL 80	111	134	122.4	0	7.4	10.6	26.8	0.06	5	0	0	0	0	0
8 JUL 80	115	135	127	0	7.4	11.4	26.8	0.15	5	0	0	0	20	40
8 JUL 80	120	135	127.6	0	7.4	12.3	26.8	0.3	5	0	0	0	0	0
8 JUL 80	109	145	125.4	0	7.4	13.1	26.3	0.56	5	20	60	100	100	100

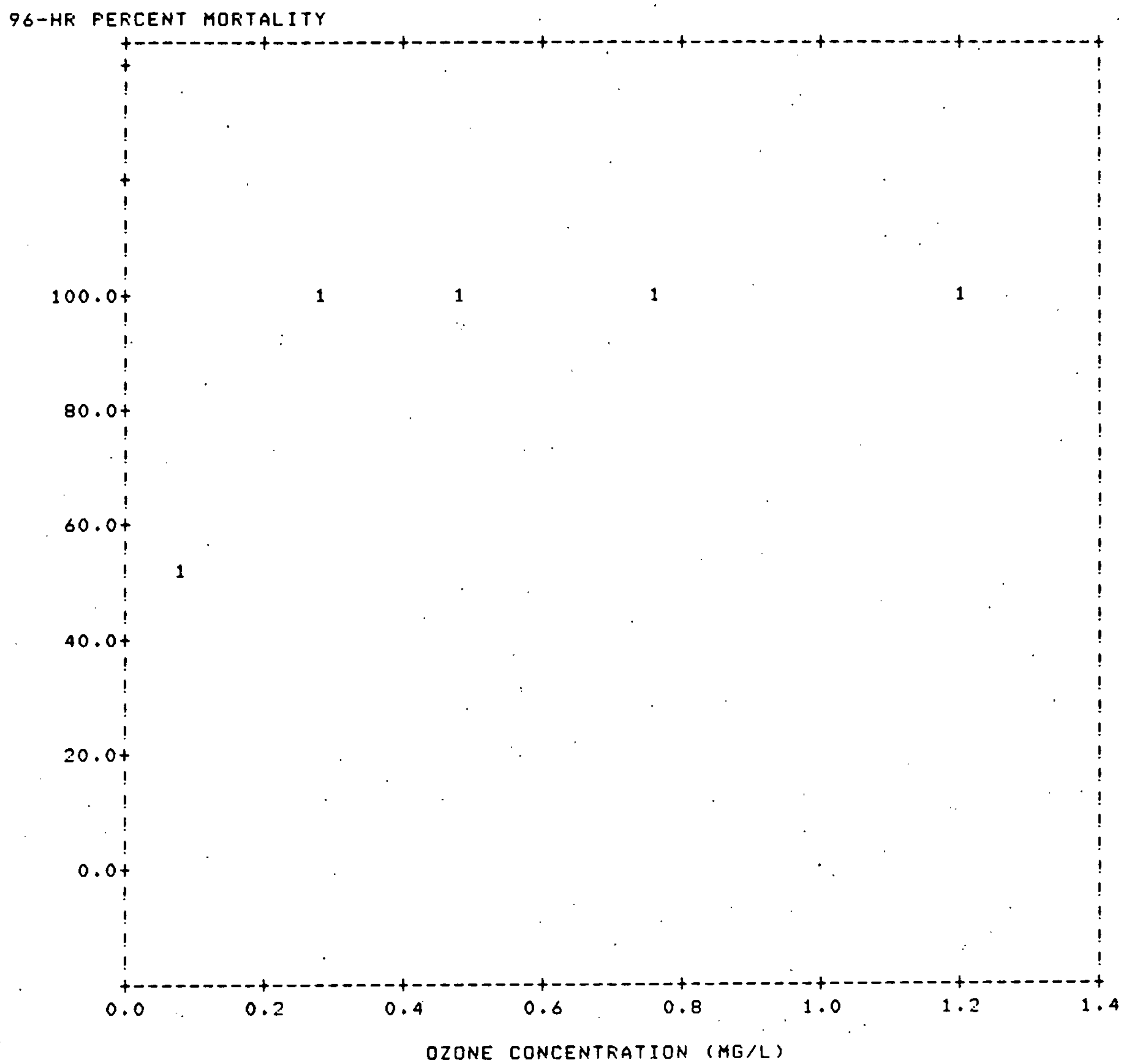


Figure 20. 96-hour percent mortality of the blueback herring, *Alosa aestivalis*, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 7 C.

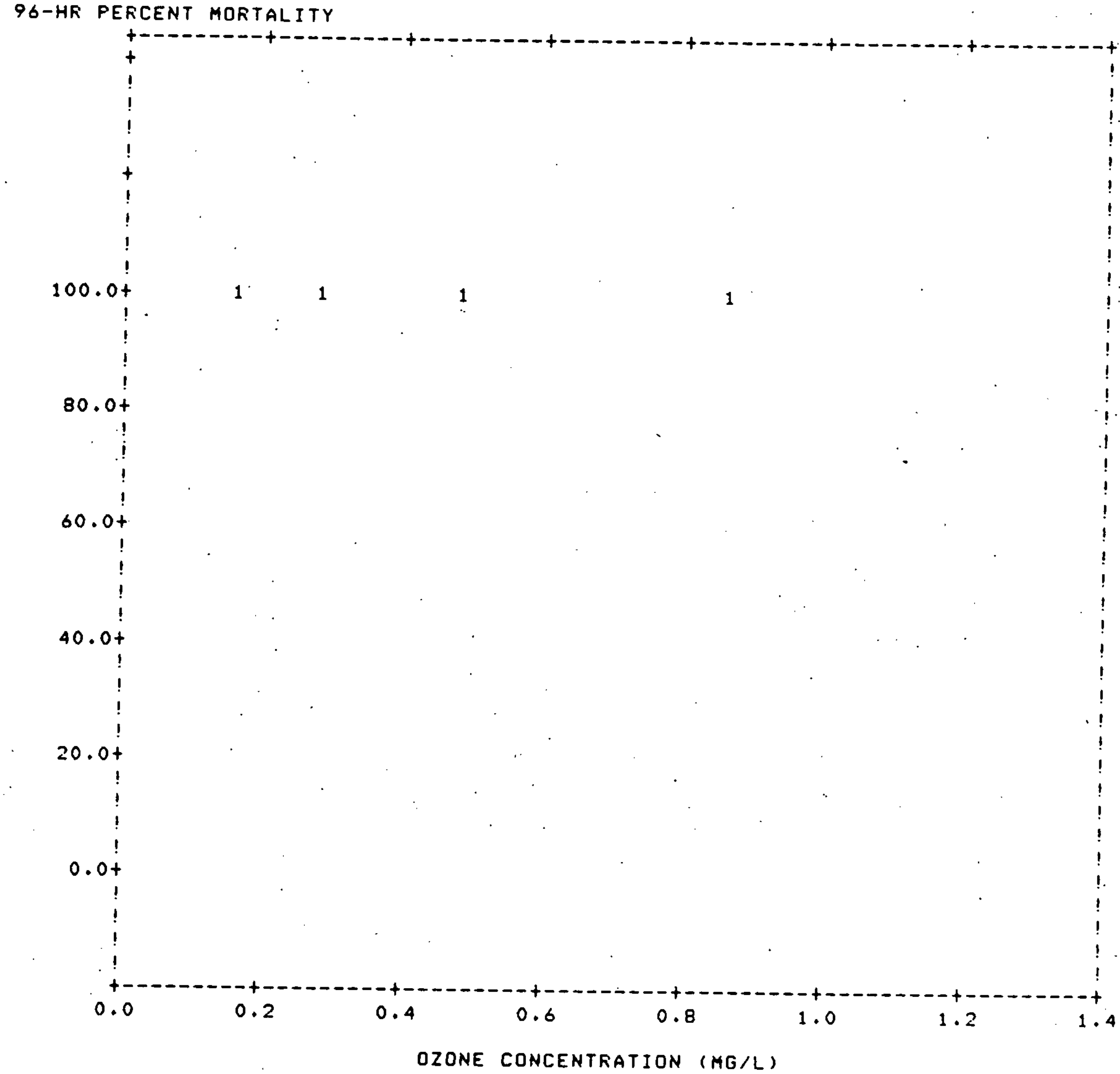


Figure 21. 96-hour percent mortality of the alewife, Alosa pseudoharengus, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 22 C.

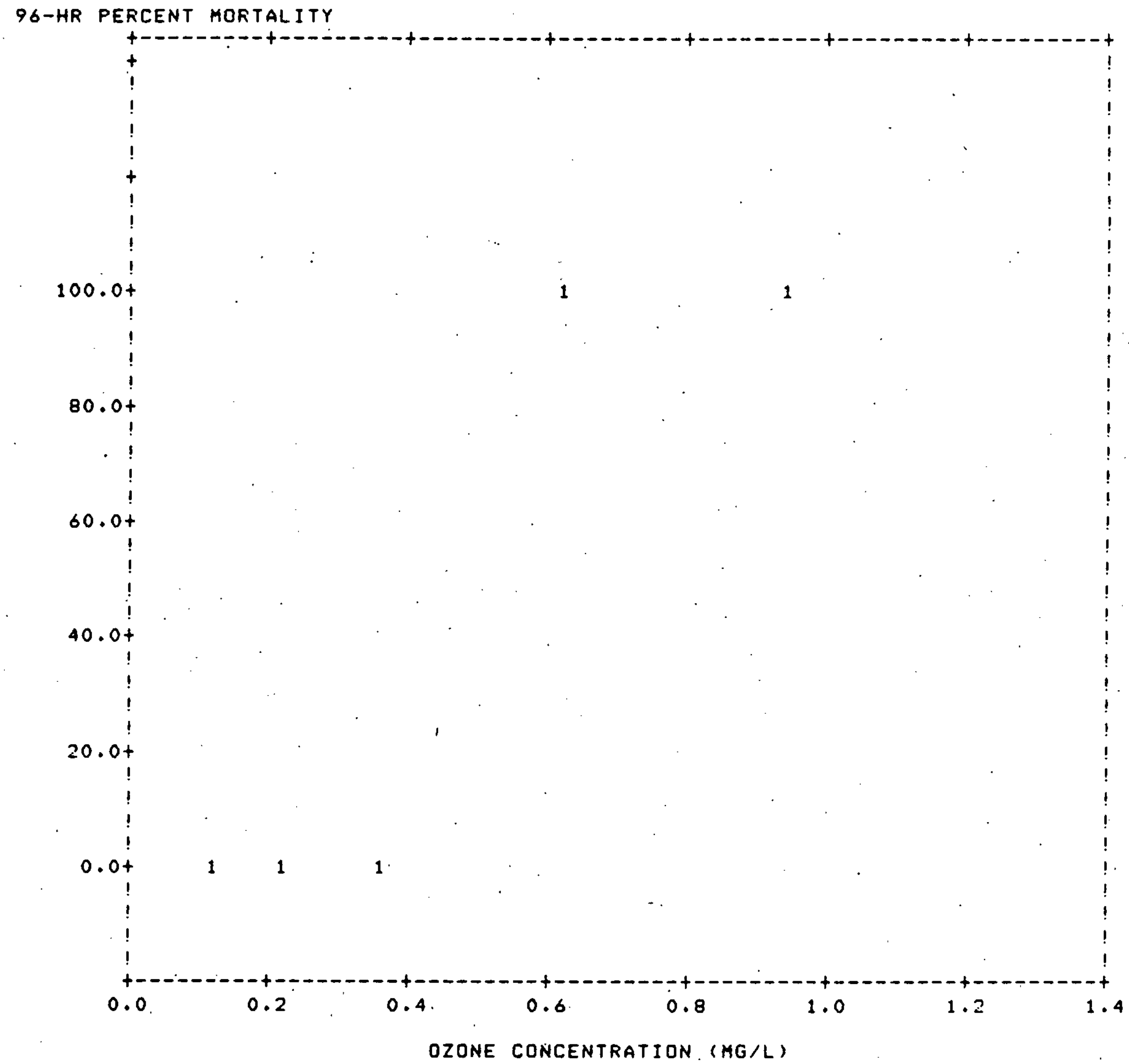


Figure 22. 96-hour percent mortality of the rainbow trout, Salmo gairdneri, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.48 mg/l ozone (measured as chlorine).
3. Test temperature was 5 C.

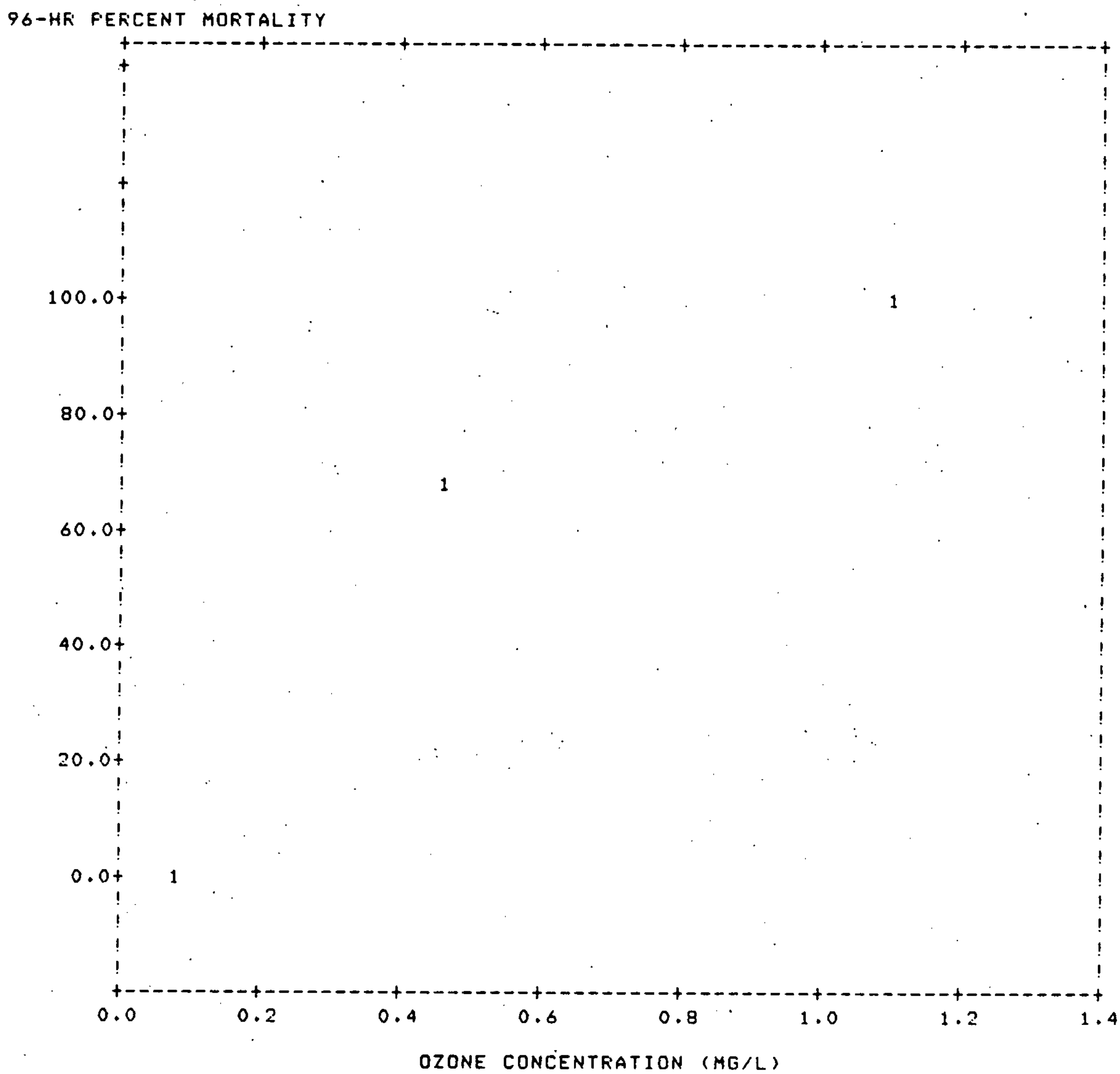


Figure 23. 96-hour percent mortality of the spottail shiner, *Notropis hudsonius*, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.36 mg/l ozone (measured as chlorine).
3. Test temperature was 6 C.

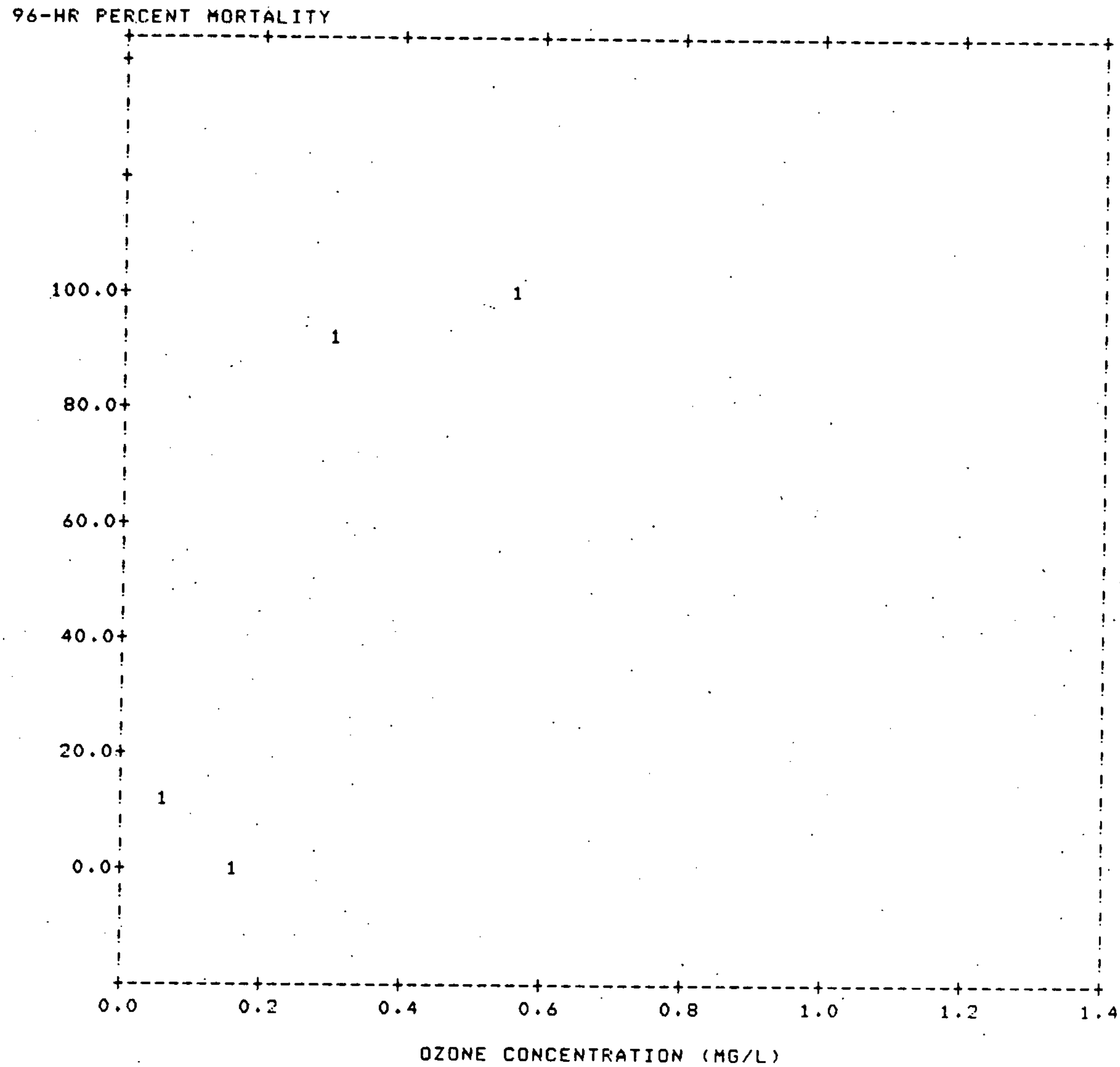


Figure 24. 96-hour percent mortality of the spottail shiner, Notropis hudsonius, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. The 2-hour intermittent LC_{50} at 96 hours is about 0.26 mg/l ozone (measured as chlorine).

3. Test temperature was 27 C.

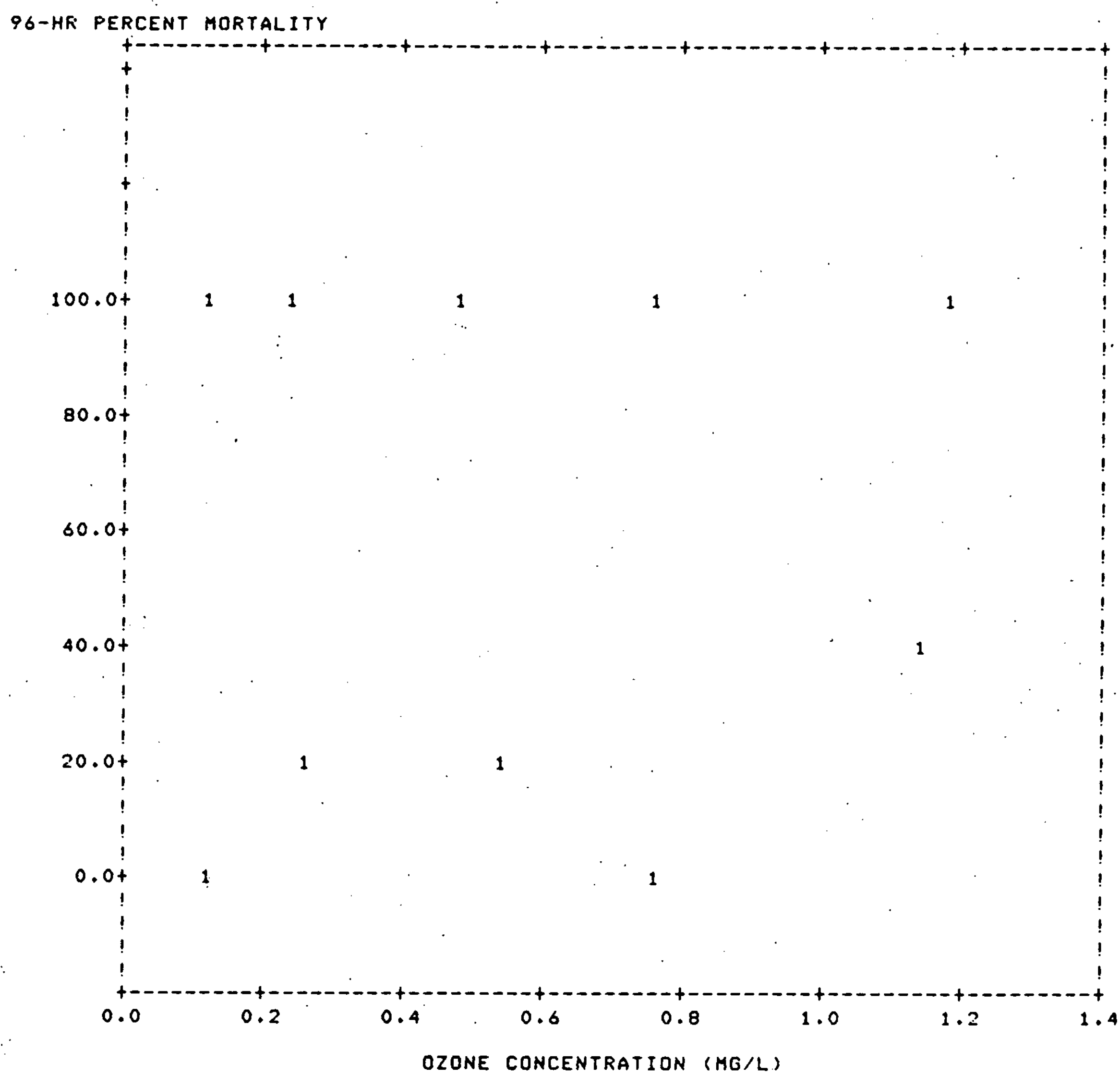


Figure 25. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Test temperature was 2 C.

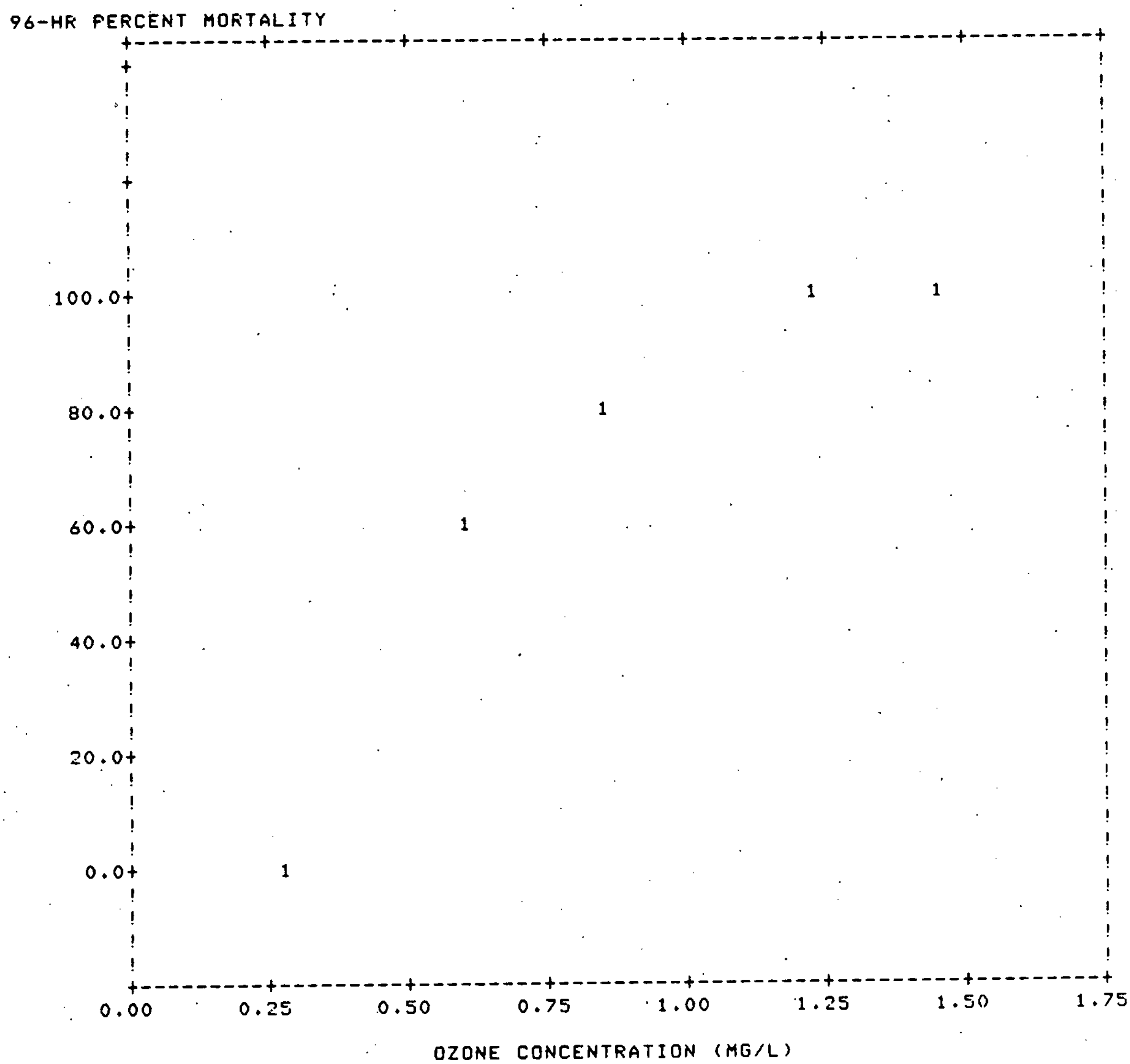


Figure 26. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours is about 0.55 mg/l ozone (measured as chlorine).
3. Test temperature was 11 C.

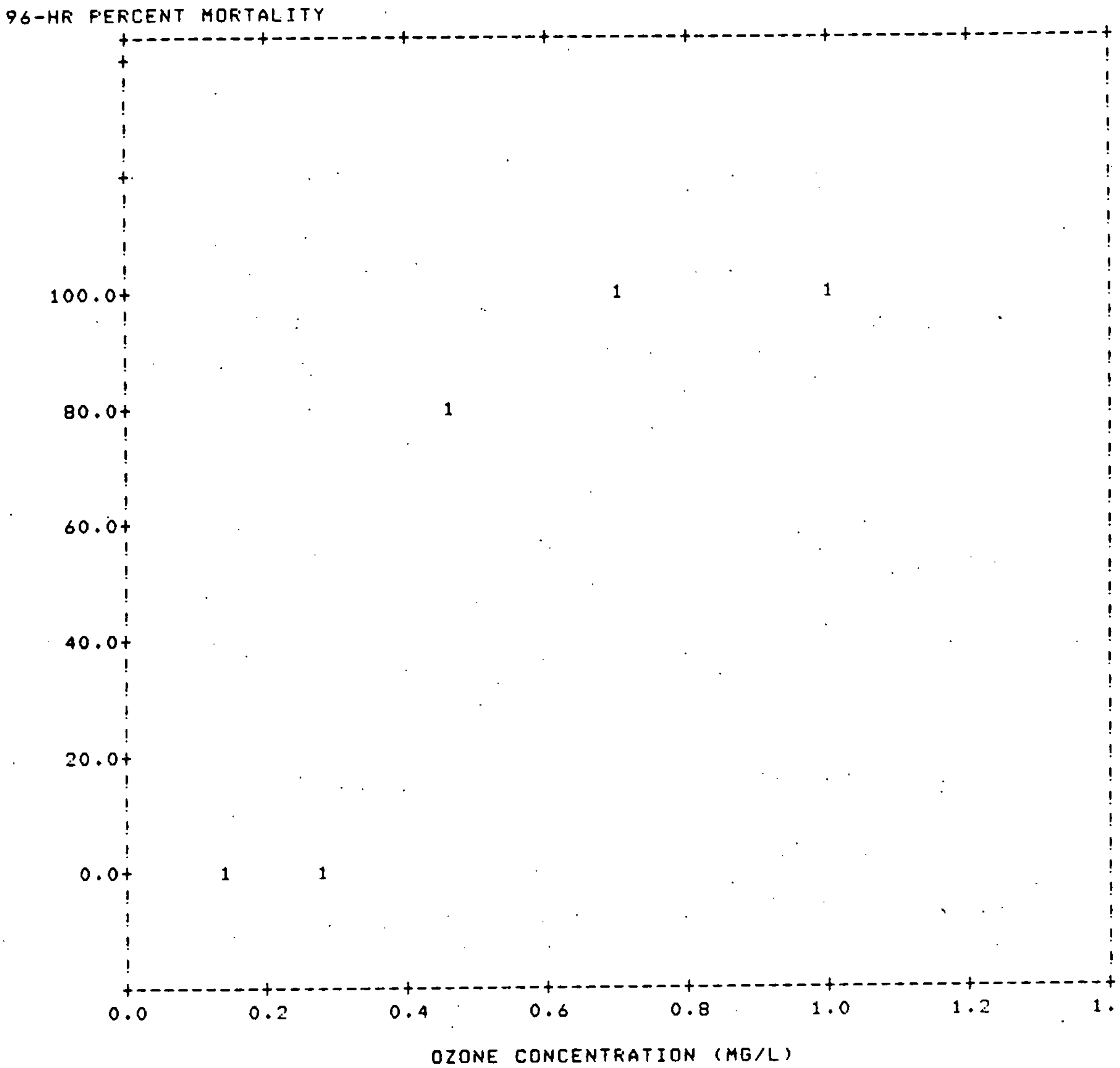


Figure 27. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours was about 0.39 mg/l ozone (measured as chlorine).
3. Test temperature was 19 C.

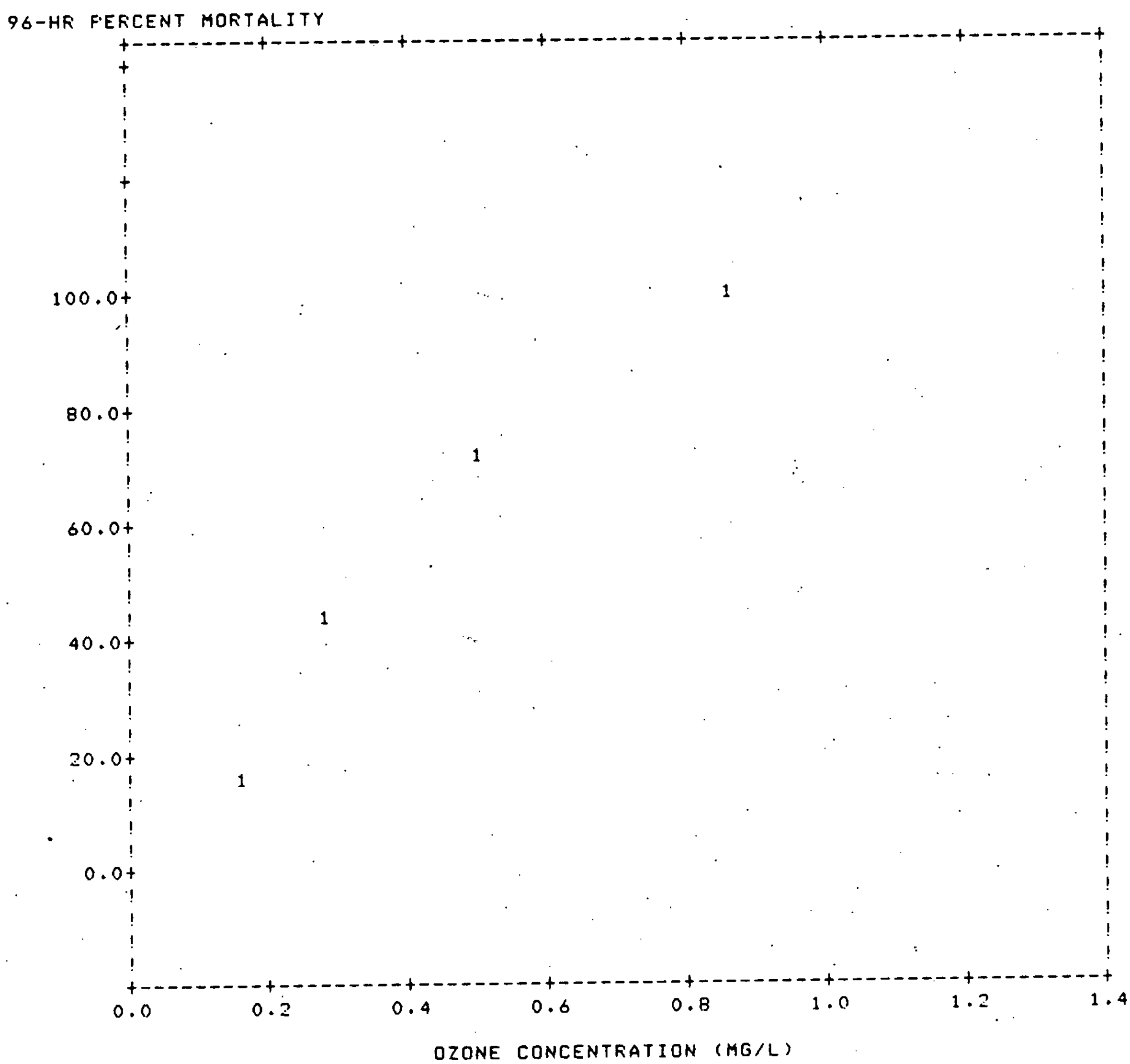


Figure 28. 96-hour percent mortality of the white perch, Morone americana, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. The 2-hour intermittent LC_{50} at 96 hours was about 0.32 mg/l ozone (measured as chlorine).

3. Test temperature was 21 C.

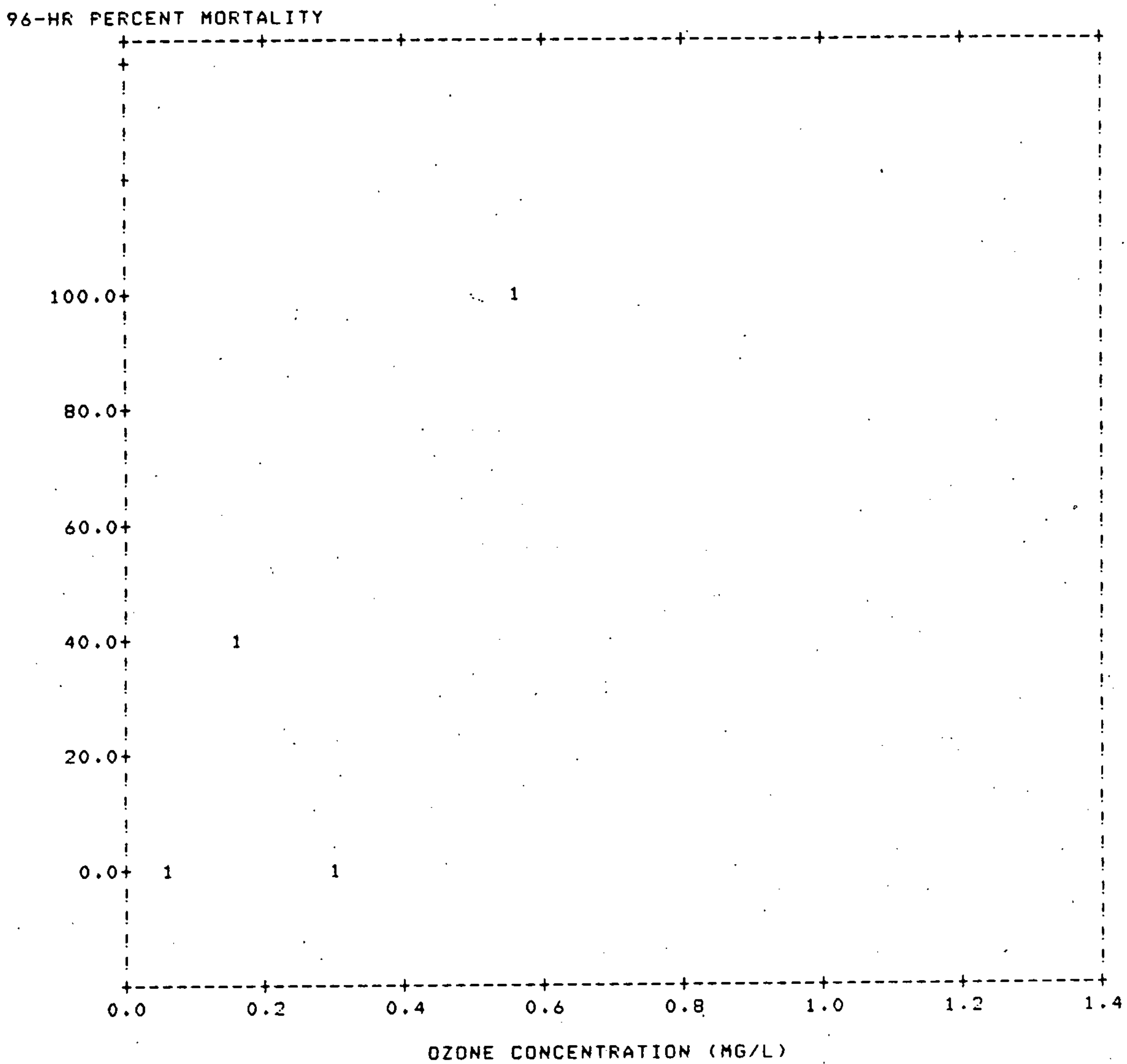


Figure 29. 96-hour percent mortality of white perch, Morone americana, for two-hour daily exposures to ozone (measured as chlorine) at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. The 2-hour intermittent LC_{50} at 96 hours was about 0.43 mg/l ozone (measured as chlorine).
3. Test temperature was 27 C.

correlation ($r = -0.60$, d.f. 2) was found between test temperature and the $ILC_{50(96,2)}$ of ozone (measured as chlorine) for white perch. However, when the results obtained at 2 C (40% mortality at 1.14 mg/l) are considered, a relationship between temperature and ozone toxicity is strongly suggested; higher $ILC_{50(96,2)}$'s are associated with lower temperatures.

AVOIDANCE RESPONSE STUDIES

Responses to chlorine and to ozone at Bergen were determined with mummichog and white perch. Responses to chlorine and ozone at Mercer were determined with blueback herring, alewife, rainbow trout, spottail shiner, banded killifish, and white perch.

Chlorine Avoidance

Bergen. Responses of mummichog and white perch to chlorine at Bergen are summarized in Table 9. Tests with mummichog were conducted over a range of average conditions which extended from 22-28.8 C; 3.5-6.3 mg/l dissolved oxygen; 0.2-1.4 ppt salinity; and 7.2-7.4 pH. Avoidance concentrations for all tests with mummichog extended from 0.01-0.15 mg/l total chlorine with a mean of 0.09 mg/l and a standard deviation of 0.05. In tests in which a 1-2 C ΔT accompanied the biocide, avoidance concentrations were between 0.05-0.15 mg/l with a mean of 0.11 mg/l and a standard deviation of 0.04. In tests conducted at ambient temperature, in which no ΔT accompanied the biocide, avoidance concentrations extended from 0.01-0.12 mg/l with a mean of 0.06 mg/l and a standard deviation of 0.06. In general, mummichog avoided higher concentrations of total chlorine in tests in which a 1-2 C ΔT accompanied the biocide than in ambient temperature tests. However, there was no significant ($P \leq 0.05$) difference between the means of ΔT tests and ambient temperature tests ($F_{1,5}=1.85$). Moreover, the highest test concentration failed to elicit avoidance in three ambient temperature tests even though the average avoidance concentration was exceeded in one such test. The avoidance concentrations are plotted against their respective test temperatures in Figure 30.

Chlorine avoidance tests with white perch were conducted over a range of average experimental temperatures which extended from 22.5-28 C;

Table 9

Summary of chlorine avoidance tests conducted at Bergen with mummichog, *Fundulus heteroclitus*; and white perch, *Morone americana*. (**=highest available test concentration (shown) did not elicit avoidance)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C)		DISSOLVED OXYGEN (MG/L)		CHLORINE AVOIDANCE CONC. (MG/L)	
							CONT.	EXP.	CONT.	EXP.	FREE	TOTAL
FUNDULUS HETEROCLITUS												
3 MAY 79	1	4	60.5	430	7.4	1	26	26	5.2	5.2	-	0.01 **
	2	4	59.8	430	7.4	1	26	26	5	5	-	0.01
25 MAY 79	1	4	84.8	430	7.4	0.3	20	22	6.4	6.3	-	0.12 **
	2	4	88.5	430	7.4	0.3	20	22	6.3	6.2	-	0.12
29 MAY 79	1	4	69	430	7.2	0.2	25	25	5.8	5.4	-	0.05
	2	4	64.5	430	7.2	0.2	25	25	5.3	5.7	-	0.05 **
20 JUN 79	1	4	76	430	7.3	1.4	27.5	28.8	4.1	3.5	-	0.05
	2	4	74.5	430	7.3	1.4	27.5	28.8	3.5	3.9	-	0.12
21 JUN 79	1	4	73.5	430	7.2	1.3	26.3	27.5	4.1	4	-	0.12
	2	4	73.3	430	7.2	1.3	26.3	27.5	4.2	4.1	-	0.15
MORONE AMERICANA												
25 APR 79	1	4	119.3	430	7.4	1	23.5	23.5	5.4	5.4	-	0.04
	2	4	118.3	430	7.4	1	23.5	23.5	5.4	5.5	-	0.05
7 MAY 79	1	4	162.8	430	7.5	1.5	26	26	5.4	5.4	-	0.02
	2	4	152.3	430	7.5	1.5	26	26	5.5	5.5	-	0.01
17 MAY 79	1	4	143.8	430	7.3	2	22.5	22.5	4.1	4.5	-	0.03
	2	4	153.3	430	7.3	2	22.5	22.5	4.3	4.7	-	0.02
18 MAY 79	1	3	142.7	430	7.3	2.5	23	23	3	3.3	-	0.20
	2	3	137.7	430	7.3	2.5	23	23	3.4	3.3	-	0.01
29 MAY 79	1	4	140	430	7.2	0.2	25	25	5	5.7	-	0.02
	2	4	131	430	7.2	0.2	25	25	4.9	5.4	-	0.02
20 JUN 79	1	3	155	430	7.3	1.4	27.5	28	4.1	3.7	-	0.01
	2	3	168.3	430	7.3	1.4	27.5	28	3.6	3.5	-	0.01

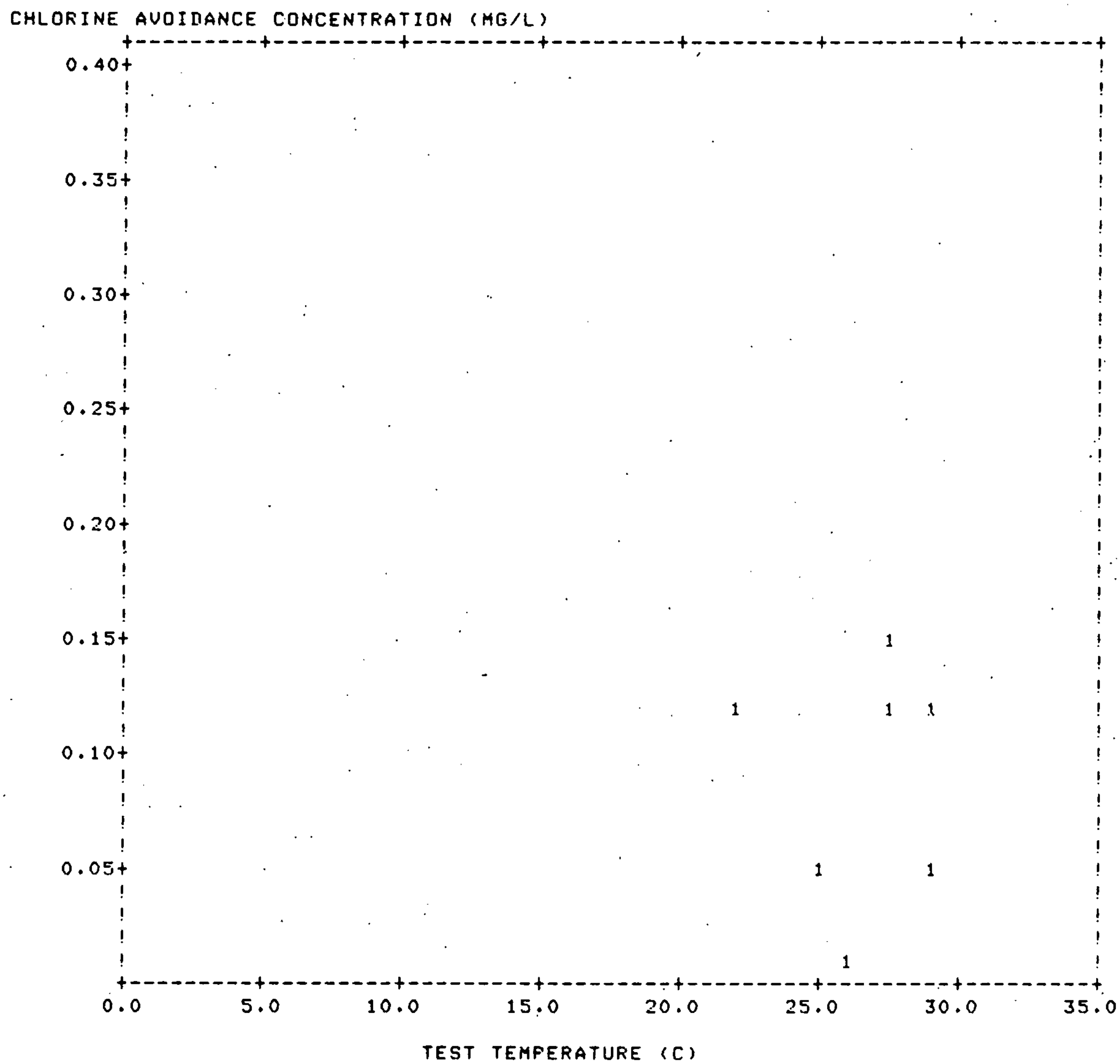


Figure 30. Total chlorine avoidance concentrations of mummichog, *Fundulus heteroclitus*, vs. test temperatures at Bergen.

Note: The number of data points in indicated numerically.

levels of dissolved oxygen from 3.3-5.7 mg/l; salinity from 0.2-2.5 ppt; and pH from 7.2-7.5. Avoidance concentrations extended from 0.10-0.20 mg/l total chlorine with a mean avoidance concentration of 0.04 mg/l. However, the standard deviation (0.05) was greater than the mean. If the 18 May 80 avoidance concentration of 0.20 mg/l is considered erroneous and removed from the calculation the mean becomes 0.02 mg/l with a standard deviation of 0.01. Of the twelve chlorine tests with white perch, two were conducted with a 0.5 C ΔT accompanying the biocide. The avoidance concentrations (both 0.01 mg/l total chlorine) in these ΔT tests were within the range of those found at ambient temperature. The avoidance concentrations of white perch are plotted against their respective test temperatures in Figure 31.

Mercer. Responses of blueback herring, alewife, rainbow trout, spottail shiner, banded killifish, and white perch to chlorine at Mercer are summarized in Table 10.

Blueback herring were tested over a range of average conditions which extended from 6.3-26 C; 5.8-11.2 mg/l dissolved oxygen; and pH from 7.2-7.9. Avoidance concentrations extended from 0.02-0.12 mg/l total chlorine, with a mean of 0.06 mg/l and a standard deviation of 0.04. The highest available test concentration failed to elicit avoidance in three tests. The avoidance concentrations are plotted against their respective test temperatures in Figure 32. In a test in which a 3.3 C ΔT accompanied the biocide, blueback herring avoided a total chlorine concentration of 0.03 mg/l, which is within the range of total chlorine concentrations avoided in ambient temperature tests. However, in a replicate test blueback herring preferred up to 0.39 mg/l total chlorine (the highest concentration tested).

Alewife were tested at an average experimental temperature of 27 C; levels of dissolved oxygen from 6.4-6.6 mg/l; and pH of 7.4. Alewife avoided 0.29 and 0.30 mg/l total chlorine. The avoidance concentrations are plotted against their test temperatures in Figure 33.

Tests with rainbow trout were conducted over a range of average experimental temperatures from 11.8-14.5 C; levels of dissolved oxygen from 9-9.6 mg/l; and pH from 7.6-7.8. Avoidance concentrations ex-

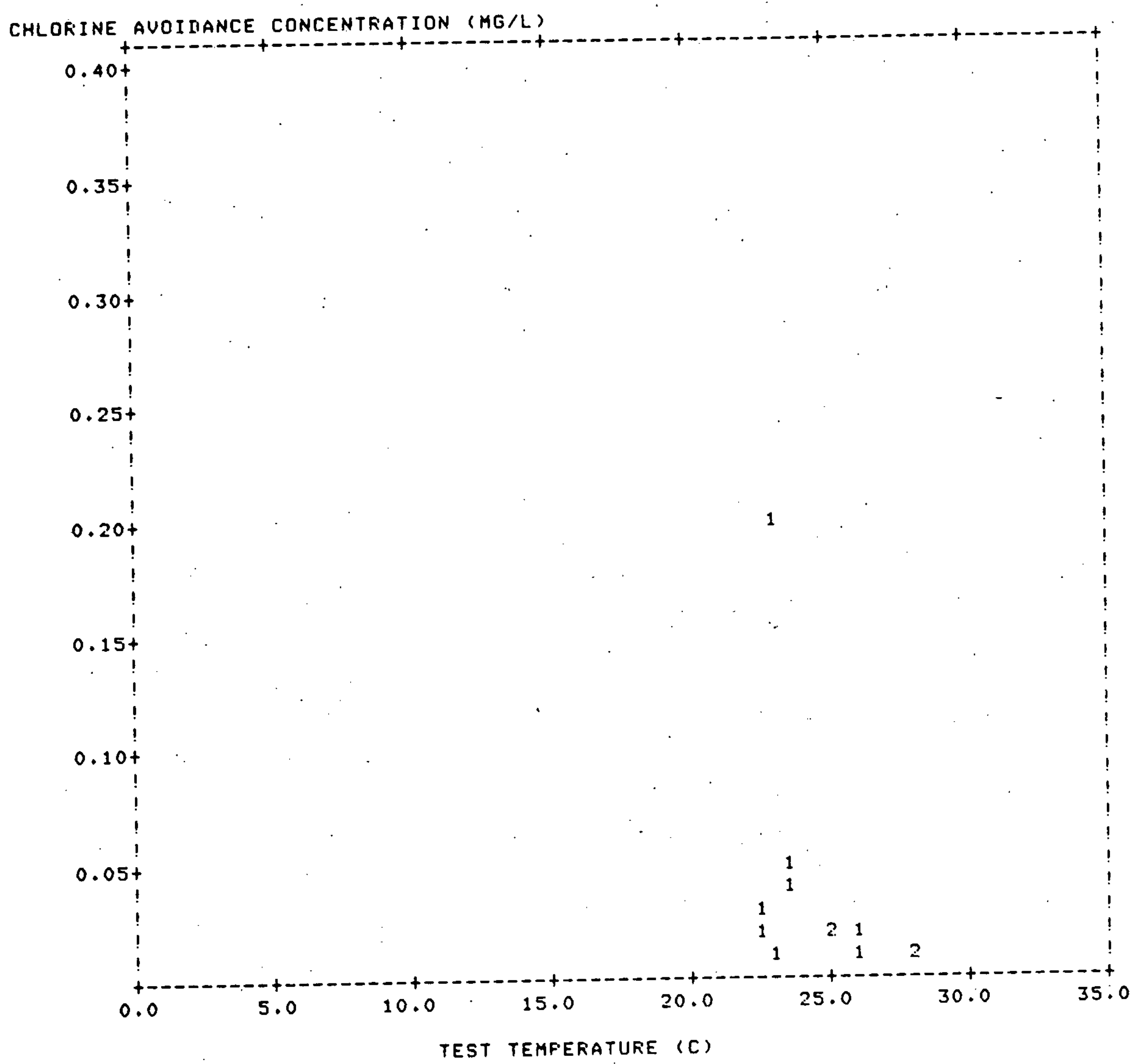


Figure 31. Total chlorine avoidance concentrations of white perch, <u>Morone americana</u>, vs. test temperatures at Bergen.

Note: The number of data points is indicated numerically.

Table 10

Summary of chlorine avoidance tests conducted at Mercer with blueback herring, Alosa aestivalis; alewife, Alosa pseudoharengus; rainbow trout, Salmo gairdneri; spottail shiner, Notropis hudsonius; banded killifish, Fundulus diaphanus; and white perch, Morone americana. (**=highest available test concentration (shown) did not elicit avoidance)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C) CONT.	TEST TEMP. (C) EXP.	DISSOLVED OXYGEN (MG/L) CONT.	DISSOLVED OXYGEN (MG/L) EXP.	CHLORINE AVOIDANCE CONC. (MG/L) FREE	CHLORINE AVOIDANCE CONC. (MG/L) TOTAL
ALOSA AESTIVALIS												
3 JAN 80	1	4	62.8	430	7.9	0	6.3	6.3	11.2	11.2	-	0.44 **
	2	3	72.3	430	7.9	0	6.3	6.3	11.2	11.2	-	0.44 **
28 APR 80	1	4	76.8	430	7.8	0	13	13	9.5	9.5	0	0.04
	2	4	85.3	430	7.8	0	13	13	9.5	9.5	0	0.02
28 APR 80	1	4	84.3	430	7.8	0	13	13	9.3	9.3	0	0.11
	2	4	86	430	7.8	0	13	13	9.2	9.2	0	0.12
29 APR 80	1	4	77.5	430	7.8	0	12.5	15.8	9.4	9.3	0.01	0.39 **
	2	4	77.5	430	7.8	0	12.5	15.8	9.4	9.3	0	0.03
1 JUL 80	1	4	101	430	7.2	0	26	26	5.8	5.9	0	0.06
	2	4	96.3	430	7.2	0	26	26	5.8	5.8	0	0.04
ALOSA PSEUDOHARENGUS												
30 JUN 80	1	3	32.7	430	7.4	0	27	27.3	6.4	6.6	0.02	0.30
	2	3	33.7	430	7.4	0	27	27.3	6.3	6.4	0.01	0.29
SALMO GAIRDNERI												
15 APR 80	1	4	70.8	430	7.6	0	12.8	12.8	9.5	9.5	0	0.11
	2	4	71.3	430	7.6	0	12.8	12.8	9.6	9.6	0	0.17
16 APR 80	1	4	64.3	430	7.7	0	11.8	11.8	9.6	9.6	0	0.06
	2	4	64.5	430	7.7	0	11.8	11.8	9.6	9.6	0	0.09
23 APR 80	1	4	70.3	430	7.8	0	14.5	14.5	9.1	9.1	0	0.18
	2	4	76.8	430	7.8	0	14.5	14.5	9.1	9	0	0.18
NOTROPIS HUDSONIUS												
14 MAY 80	1	4	76.8	430	7.1	0	18.3	18.3	7.5	7.5	0	0.10
	2	4	82.8	430	7.1	0	18.3	18.3	7.5	7.5	0	0.11
2 JUL 80	1	4	32	430	7.3	0	26.5	26.5	6.1	6.2	0	0.16
	2	4	33.3	430	7.3	0	26.5	26.5	6.2	6.2	0	0.16
FUNDULUS DIAPHANUS												
24 JAN 80	1	4	86	430	8.1	0	3.3	3.3	11.8	11.9	0.77	2.00
	2	4	85.5	430	8.1	0	3.3	3.3	11.8	12	1.05	2.05
26 FEB 80	1	4	93	430	8	0	6.5	6	11.1	11.1	-	2.12 **
	2	4	93.8	430	8	0	6.5	6	11.1	11.1	-	1.75
28 FEB 80	1	4	91	430	7.8	0	4.5	4.5	11.2	11.3	0.15	2.03
	2	4	64	430	7.8	0	4.5	4.5	11.2	11.3	0.15	1.93
13 MAR 80	1	4	61.5	430	7.9	0	6	6	11.2	11.2	0.07	2.17
	2	4	67.3	430	7.9	0	6	6	11.2	11.2	0.13	1.60

Table 10 (continued)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C) CONT.	TEST TEMP. (C) EXP.	DISSOLVED OXYGEN (MG/L) CONT.	DISSOLVED OXYGEN (MG/L) EXP.	CHLORINE AVOIDANCE CONC. (MG/L) FREE	CHLORINE AVOIDANCE CONC. (MG/L) TOTAL
MORONE AMERICANA												
27 DEC 79	1	3	63.3	430	7.8	0	7.8	7.8	11	11.2	-	0.10
	2	3	65	430	7.8	0	7.8	7.8	11	11.2	-	0.10
20 MAR 80	1	4	71.3	430	7.9	0	7.5	7.8	10.4	10.4	0	0.25
	2	4	69.5	430	7.9	0	7.5	7.8	10.4	10.4	0	0.31
3 APR 80	1	4	74.3	430	7.4	0	10.3	10.3	10.5	10.5	0	0.17
	2	4	75.8	430	7.4	0	10	11	10.6	10.6	0	0.10
27 MAY 80	1	3	126.7	430	7.2	0	21	21	8.3	8.3	0	0.21
	2	3	127.7	430	7.2	0	21	21	8.3	8.3	0	0.15
18 JUN 80	1	3	101.3	430	8.4	0	23.8	23.8	8.5	8.6	0	0.23
	2	3	102.7	430	8.4	0	23.5	23.5	8.2	8.2	0	0.16
4 JUL 80	1	4	32.3	430	7.1	0	26.8	26.8	6.4	6.4	0	0.23
	2	4	31.8	430	7.1	0	26.8	26.8	6.3	6.2	0.01	0.36

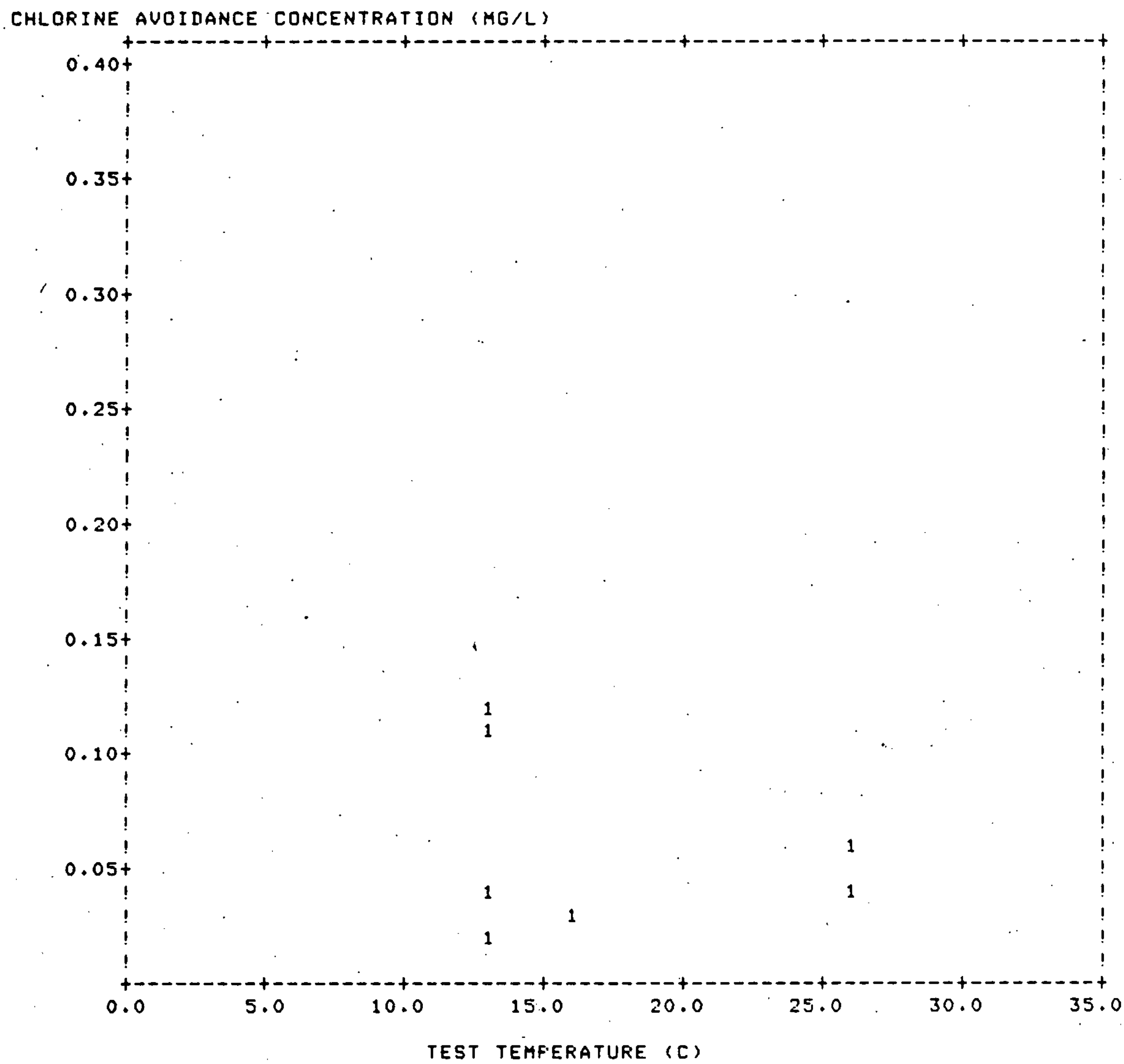


Figure 32. Total chlorine avoidance concentrations of blueback herring, *Alosa aestivalis*, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

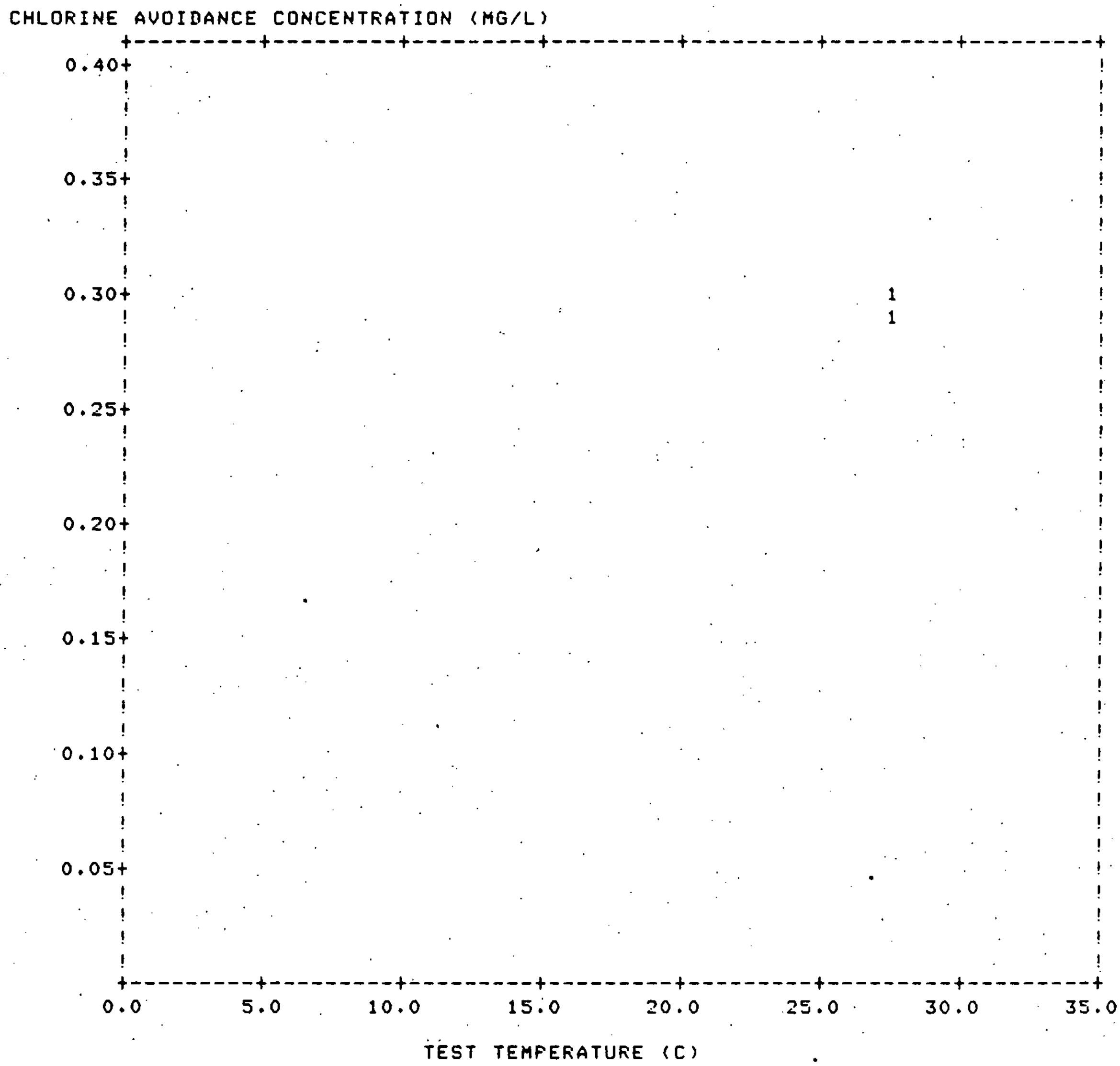


Figure 33. Total chlorine avoidance concentrations of alewife, Alosa pseudoharengus, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

tended from 0.06-0.18 mg/l total chlorine with a mean avoidance concentration of 0.13 mg/l and a standard deviation of 0.05. The avoidance concentrations are plotted against their respective test temperatures in Figure 34.

Spottail shiner were tested at average experimental temperatures of 18.3 and 26.5 C; respective levels of dissolved oxygen of 7.5 and 6.2 mg/l; and respective pH of 7.1 and 7.3. At 18.3 C, spottail shiner avoided 0.10 and 0.11 mg/l total chlorine. A slightly higher concentration (0.16 mg/l total chlorine) was avoided at 26.5 C. The mean avoidance concentration was 0.13 mg/l total chlorine and the standard deviation was 0.03. The avoidance concentrations are plotted against their respective test temperatures in Figure 35. Correlation analysis showed a highly significant ($P \leq 0.01$) direct relationship between avoidance concentration and test temperature ($r = 0.992$ with 2 d.f.).

Banded killifish were tested over a range of average conditions which extended from 3.3-6 C; 11.1-12 mg/l dissolved oxygen; and pH from 7.9-8.1. Chlorine avoidance concentrations of banded killifish were considerably higher than those of other fishes tested. Avoidance concentrations ranged from 1.60-2.17 mg/l total chlorine with a mean of 1.93 mg/l and a standard deviation of 0.19. The highest test concentration failed to elicit avoidance in one of the tests even though the average avoidance concentration was exceeded. The avoidance concentrations are plotted against their respective test temperatures in Figure 36.

White perch were tested over a range of average conditions which extended from 7.8-26.8 C; 6.2-11.2 mg/l dissolved oxygen; and pH from 7.1-8.4. Avoidance concentrations extended between 0.10-0.36 mg/l total chlorine with a mean of 0.20 mg/l and a standard deviation of 0.08. The avoidance concentrations are plotted against their respective temperatures in Figure 37.

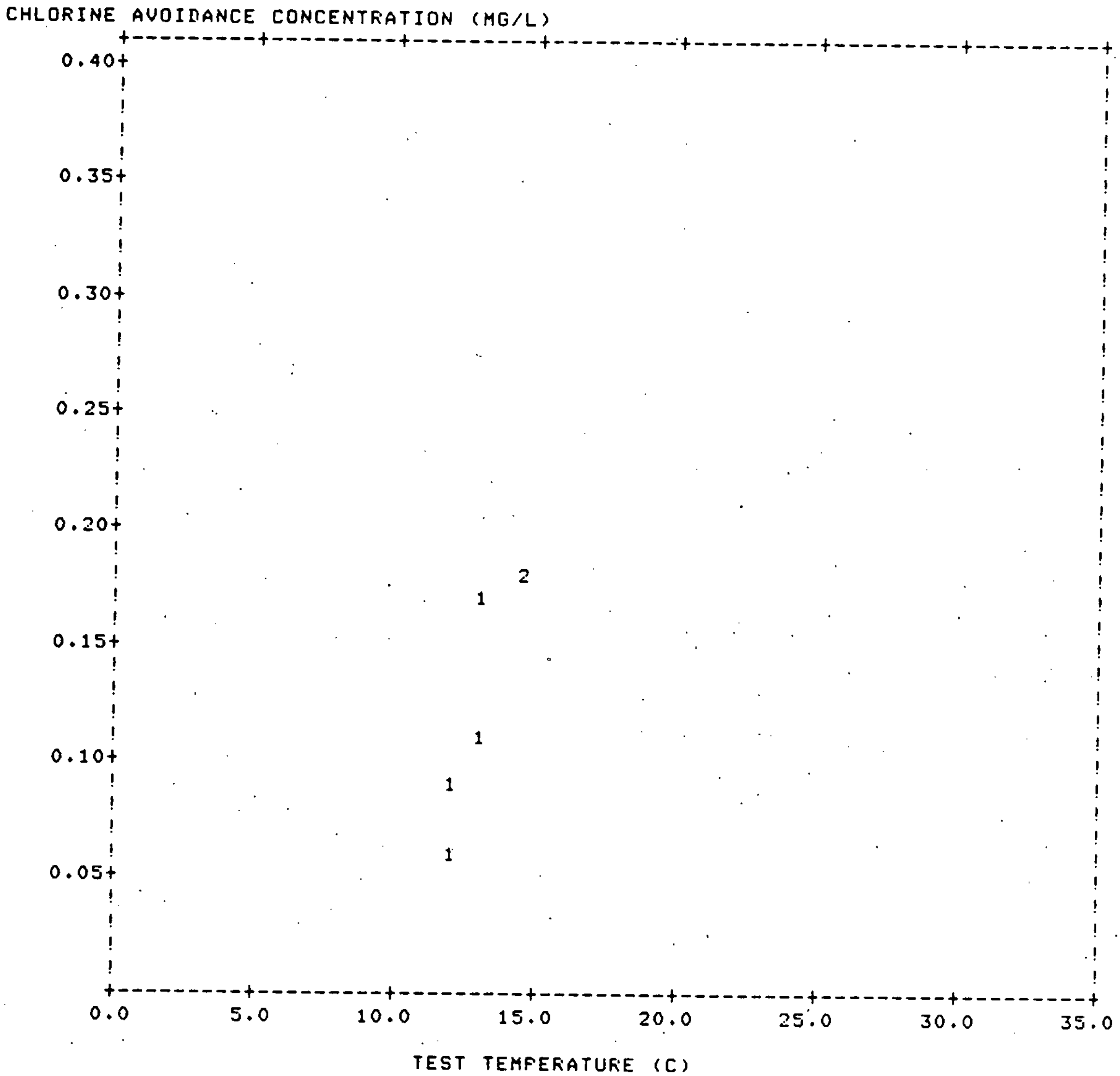


Figure 34. Total chlorine avoidance concentrations of rainbow trout, *Salmo gairdneri*, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

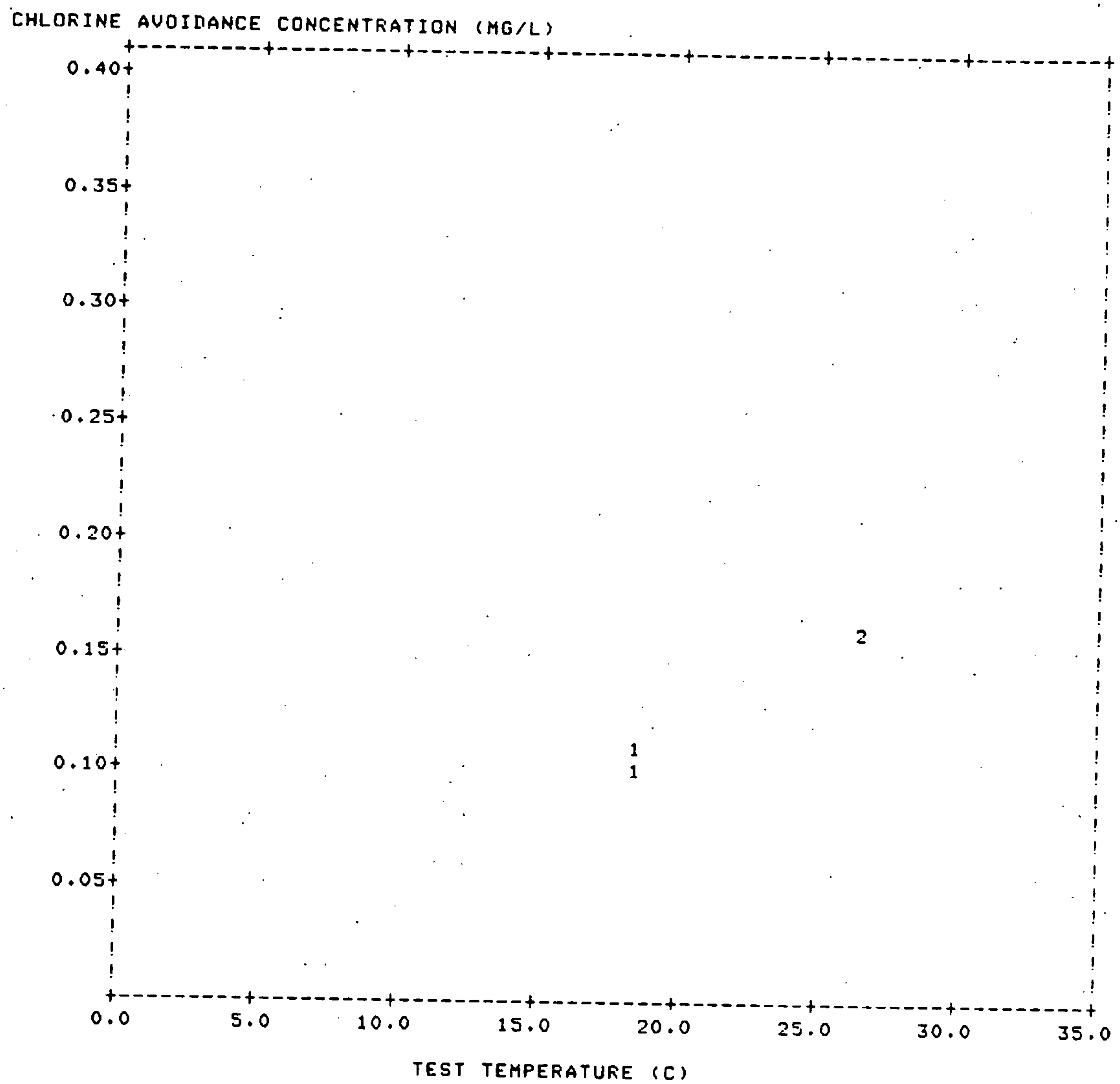


Figure 35. Total chlorine avoidance concentrations of spottail shiner, <u>Notropis hudsonius</u>, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

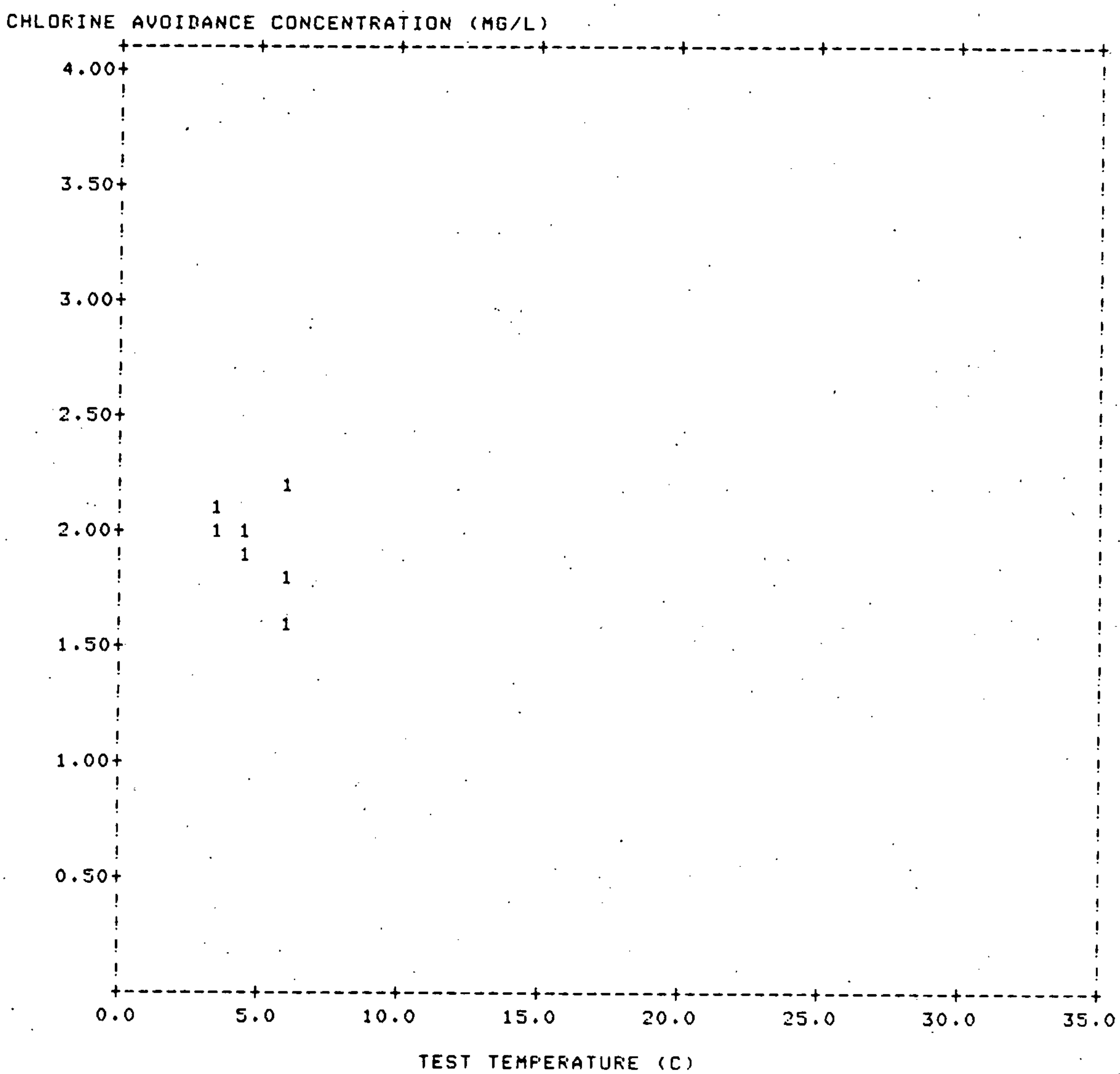


Figure 36. Total chlorine avoidance concentrations of banded killifish, *Fundulus diaphanus*, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

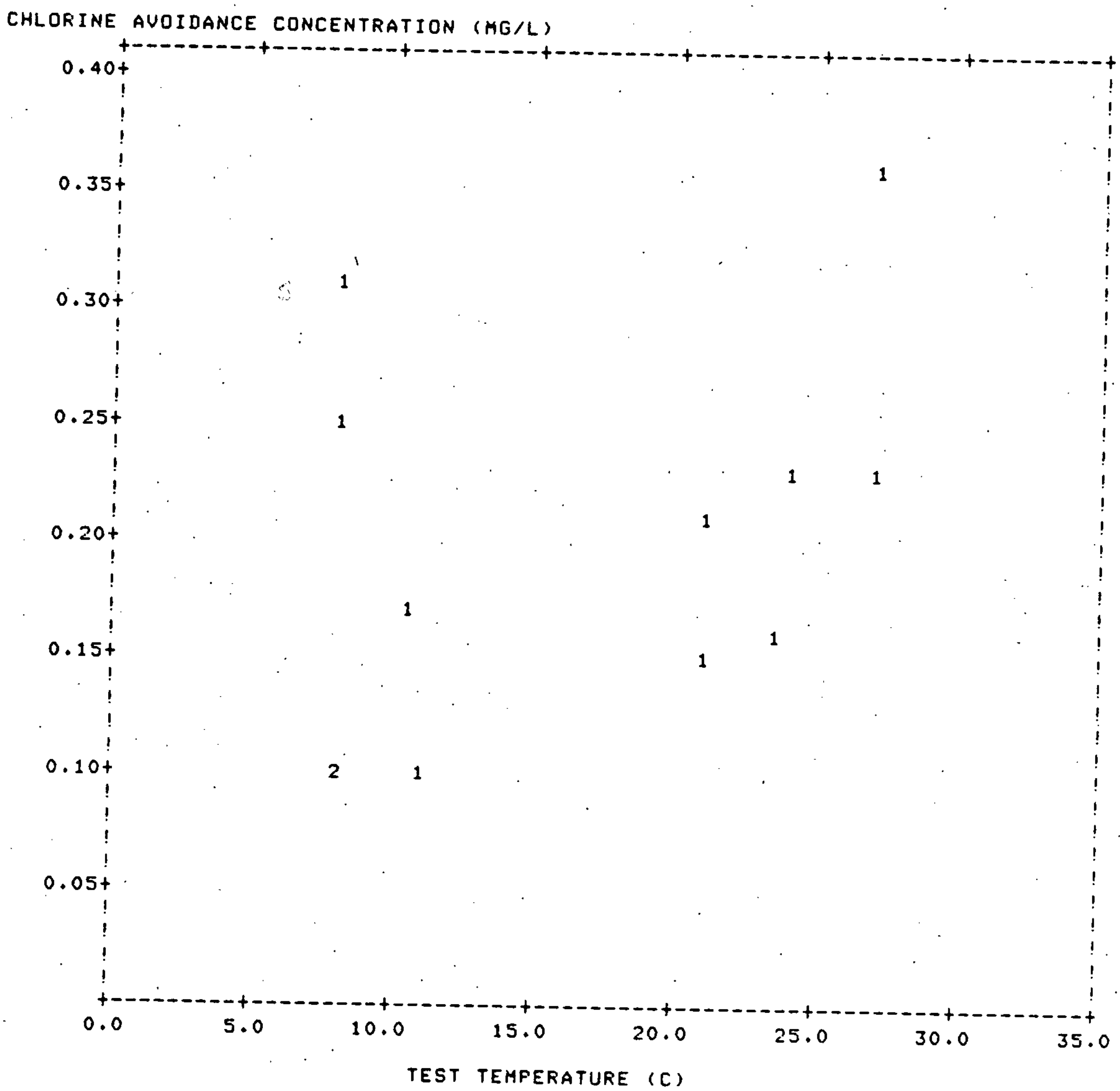


Figure 37. Total chlorine avoidance concentrations of white perch, *Morone americana*, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

Ozone Avoidance

Bergen. Responses of mummichog and white perch to ozone (measured as chlorine) at Bergen are summarized in Table 11. All tests with mummichog were conducted with a 1.5-2.8 C ΔT accompanying the experimental concentration. Average experimental temperatures extended from 26-28.5 C; levels of dissolved oxygen from 6.5 to greater than 20 mg/l; salinities from 1.4-2.5 ppt; and pH from 7.2-7.3. In all but one test (in which the avoidance concentration was 0.22 mg/l), the highest concentrations available failed to elicit an avoidance response. In fact, at higher concentrations, mummichog were observed feeding on entrained copepods in the ozonated portion of the test apparatus.

Ozone tests with white perch were conducted at average experimental temperatures extending from 20-27 C; levels of dissolved oxygen from 6.7-11.8 mg/l; salinities from 1-2.5 ppt; and pH from 7.3-7.6. The avoidance concentrations extended from 0.04-0.30 mg/l ozone (measured as chlorine) with a mean of 0.10 mg/l ozone (measured as chlorine) and a standard deviation of 0.09. The highest available test concentration failed to elicit avoidance in two tests. The number of data points was insufficient for statistical analysis. Several ozone avoidance tests in which a ΔT accompanied the experimental concentration were attempted in June, 1979, but due to a malfunction of the ozonator and poor water quality (white perch died in the untreated water) none were completed. The ozone avoidance concentrations are plotted against their respective test temperatures in Figure 38.

Mercer. Responses of blueback herring, alewife, rainbow trout, spottail shiner, banded killifish, and white perch to ozone (measured as chlorine) at Mercer are summarized in Table 12.

Table 11

Summary of ozone (measured as chlorine) avoidance tests conducted at Bergen with mummichog, Fundulus heteroclitus; and white perch, Morone americana. (*=level of dissolved oxygen exceeded 20 mg/l; **=highest available test concentration (shown) did not elicit avoidance.)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C) CONT.	TEST TEMP. (C) EXP.	DISSOLVED OXYGEN (MG/L) CONT.	DISSOLVED OXYGEN (MG/L) EXP.	OZONE AVOIDANCE CONCENTRATION (MG/L)
FUNDULUS HETEROCLITUS											
21 JUN 79	1	4	73.5	430	7.2	1.5	27	28.5	3.8	6.7	0.22 **
	2	4	69.8	430	7.2	1.5	27	28.5	3.9	6.5	0.22 **
22 JUN 79	1	4	70	430	7.2	1.4	26	28.5	5.1	11.6	0.42 **
	2	4	68	430	7.2	1.4	26	28.5	5.7	*	0.42 **
25 JUN 79	1	4	66.3	430	7.3	1.8	24.5	26.3	5.6	9.8	0.34 **
	2	4	64.8	430	7.3	1.8	24.5	26	6	11.6	0.34 **
25 JUN 79	1	4	74.5	430	7.3	1.8	24.5	26.3	5.9	*	0.37 **
	2	4	65	430	7.3	1.8	24.5	26.3	5.6	*	0.37 **
26 JUN 79	1	4	75.3	430	7.3	2.5	25.5	28	3.6	9.9	0.29 **
	2	4	66.5	430	7.3	2.5	25.5	28	3.6	9.9	0.22
27 JUN 79	1	4	69.8	430	7.3	2.5	25.5	28.3	3.1	*	0.36 **
	2	4	73.3	430	7.3	2.5	25.5	28.3	3	*	0.36 **
MORONE AMERICANA											
25 APR 79	1	4	122.5	430	7.4	1	20	20	7.4	9.3	0.05
	2	4	132.3	430	7.4	1	20	20	7.4	10.4	0.05
30 APR 79	1	4	144.3	430	7.4	1	25	25	5	10	0.04
	2	4	148.8	430	7.4	1	25	25	5	11.8	0.04
7 MAY 79	1	4	156.5	430	7.6	1.5	27	27	7.2	7.9	0.06 **
	2	4	169	430	7.6	1.5	27	27	7.1	7.9	0.06
17 MAY 79	1	4	135.3	430	7.3	2	24	24	5.7	6.7	0.10 **
	2	4	150.5	430	7.3	2	24	24	6.4	7	0.06
18 MAY 79	1	3	138	430	7.3	2.5	23	23	2.7	10.5	0.30
	2	3	131.7	430	7.3	2.5	23	23	3.7	11.6	0.21

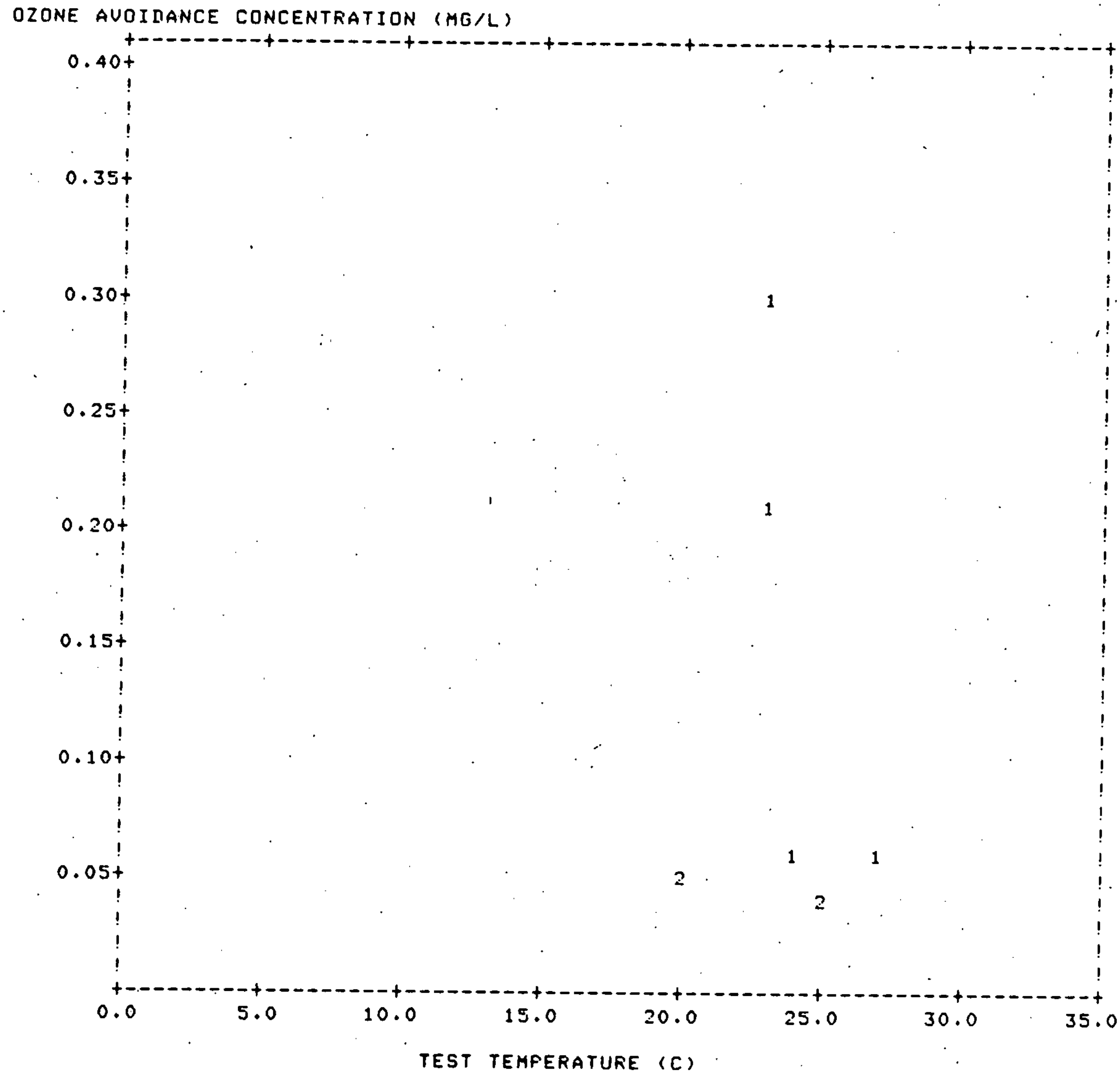


Figure 38. Ozone avoidance concentrations of white perch, <u>Morone americana</u>, vs. test temperatures at Bergen.

Notes:

1. The number of data points is indicated numerically.
2. Ozone is measured as chlorine.

Table 12

Summary of ozone (measured as chlorine) avoidance tests conducted at Mercer with blueback herring, *Alosa aestivalis*; alewife, *Alosa pseudoharengus*; rainbow trout, *Salmo gairdneri*; spottail shiner, *Notropis hudsonius*; banded killifish, *Fundulus diaphanus*; and white perch, *Morone americana*. (**=highest available test concentration (shown) did not elicit avoidance)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C) CONT.	TEST TEMP. (C) EXP.	DISSOLVED OXYGEN (MG/L) CONT.	DISSOLVED OXYGEN (MG/L) EXP.	OZONE AVOIDANCE CONCENTRATION (MG/L)
ALOSA AESTIVALIS											
29 DEC 79	1	0	-	430	7.7	0	-	-	-	-	-
	2	4	70	430	7.7	0	6.8	6.8	10.8	11.9	0.04
4 JAN 80	1	4	72	430	8	0	5.5	5.5	11.2	12.7	0.32 **
	2	0	-	430	8	0	-	-	-	-	-
28 APR 80	1	4	84.3	430	7.8	0	13.5	13.5	9.2	10.1	0.08
	2	4	78.8	430	7.8	0	13.5	13.5	9.2	9.5	0.04
29 APR 80	1	4	87.5	430	7.8	0	13	15.5	10	11.6	0.16
	2	4	84.3	430	7.8	0	13	15.3	10	11.6	0.12
9 MAY 80	1	4	84.3	430	7.1	0	17.3	17.3	8.3	8.5	0.01
	2	4	80.5	430	7.1	0	17.3	17.3	8.2	8.6	0.03
1 JUL 80	1	4	79.8	430	7.2	0	26.5	26.5	6.1	9.2	0.01
	2	4	88.3	430	7.2	0	26.5	26.5	6.2	9	0.01
ALOSA PSEUDOHARENGUS											
1 JUL 80	1	4	39.8	430	7.2	0	27.3	27.3	7	11.4	0.06
	2	4	39.8	430	7.2	0	27.3	27.3	7	11.2	0.04
SALMO GAIRDNERI											
15 APR 80	1	4	72.3	430	7.6	0	13	13	9.8	10.4	0.05
	2	4	74	430	7.6	0	13	13	9.8	10.5	0.06
24 APR 80	1	4	76.3	430	7.8	0	15.5	15.5	8.7	9.6	0.14
	2	4	77	430	7.8	0	15	15	8.8	9.6	0.05
NOTROPIS HUDSONIUS											
15 MAY 80	1	4	79.3	430	7	0	18.3	18.3	7.4	9.6	0.17
	2	4	75.3	430	7	0	18.3	18.3	7.3	9.5	0.16
3 JUL 80	1	4	32.5	430	7.2	0	26	26	6.2	9.9	0.05
	2	4	33	430	7.2	0	26	26	6.2	10.1	0.06
FUNDULUS DIAPHANUS											
17 JAN 80	1	4	90.8	430	8.1	0	6.3	6.3	11.2	11.9	0.21
	2	4	91.3	430	8.1	0	6.3	6.3	11.2	11.9	0.19
18 JAN 80	1	4	95	430	8.1	0	7	7	10.5	11.2	0.21
	2	4	97.5	430	8.1	0	7	7	10.5	11.3	0.18
26 FEB 80	1	4	83.3	430	8	0	6	6.5	11.1	-	0.20 **
	2	4	81.8	430	8	0	6.5	6	11.1	-	0.20
27 FEB 80	1	4	79.5	430	8.2	0	7	7	11.4	12.5	0.10
	2	4	89.3	430	8.2	0	7	7	11.4	12.9	0.14
14 MAR 80	1	4	69	430	7.9	0	4.5	5	10.9	12.5	0.36
	2	4	66.3	430	7.9	0	4.8	5.3	10.9	12.1	0.16

Table 12 (continued)

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C) CONT.	TEST TEMP. (C) EXP.	DISSOLVED OXYGEN (MG/L) CONT.	DISSOLVED OXYGEN (MG/L) EXP.	OZONE AVOIDANCE CONCENTRATION (MG/L)
MORONE AMERICANA											
29 DEC 79	1	4	79.3	430	7.7	0	6.8	6.8	10.8	11.7	0.14
	2	0	-	430	7.7	0	-	-	-	-	-
21 MAR 80	1	4	80	430	7.9	0	8	8	10.4	12.2	0.20
	2	4	72.3	430	7.9	0	8	8	10.4	12.3	0.20
2 APR 80	1	4	89	430	7.6	0	8.5	8.5	10.7	12.2	0.20
	2	4	80	430	7.6	0	8.5	8.5	10.7	12.3	0.24
16 JUN 80	1	4	85.8	430	7.3	0	22.5	22.5	7.2	9.9	0.12
	2	4	88.3	430	7.3	0	22.5	22.5	7.3	9.7	0.15
4 JUL 80	1	4	36.8	430	7.1	0	25.8	25.8	6.4	9.7	0.06
	2	4	36.8	430	7.1	0	25.8	25.8	6.2	9.8	0.09

Blueback herring were tested over a range of average conditions which extended from 5.5-26.5 C; 8.5-12.7 mg/l dissolved oxygen; and pH from 7.1-8. Avoidance concentrations in tests in which no ΔT accompanied the biocide extended from 0.01-0.08 mg/l ozone (measured as chlorine) with a mean of 0.03 mg/l and a standard deviation of 0.03. In tests (2) in which a 2-3 C ΔT accompanied the experimental ozone concentration, blueback herring avoided concentrations of ozone (measured as chlorine) of 0.12 and 0.16 mg/l respectively, with a mean of 0.14 mg/l and a standard deviation of 0.03. Analysis of variance showed that the mean ozone avoidance concentration with a ΔT was significantly ($P \leq 0.05$) greater than the mean avoidance concentration at ambient temperature ($F_{1,7}$=27.39). The highest available test concentration failed to elicit avoidance in one ambient temperature test even though the avoidance concentration exceeded the average avoidance concentration for all tests combined. The avoidance concentrations are plotted against the test temperatures in Figure 39.

Tests with alewife were conducted at an average temperature of 27.3 C; 11.2 and 11.4 mg/l dissolved oxygen; and pH 7.2. Alewife avoided 0.04 and 0.06 mg/l ozone (measured as chlorine). The avoidance concentrations are plotted against their test temperatures in Figure 40.

Tests with rainbow trout were conducted over a range of average experimental temperatures from 13-15.5 C; 9.6-10.5 mg/l dissolved oxygen; and pH from 7.6-7.8. Avoidance concentrations extended from 0.05-0.14 mg/l ozone (measured as chlorine) with a mean avoidance concentration of 0.08 mg/l and a standard deviation of 0.04. The avoidance concentrations are plotted against their respective test temperatures in Figure 41.

Spottail shiner were tested at average experimental temperatures of 18.3 and 26 C; levels of dissolved oxygen from 9.5-10.1 mg/l; and pH 7 and 7.2. At 18.3 C, spottail shiner avoided 0.16 and 0.17 mg/l ozone (measured as chlorine). Considerably lower concentrations (0.05 and 0.06 mg/l ozone, measured as chlorine) were avoided at 26 C. The mean avoidance concentration was 0.11 mg/l ozone (measured as chlorine) and the standard deviation was 0.06. The avoidance concentrations are plotted against their respective test temperatures in

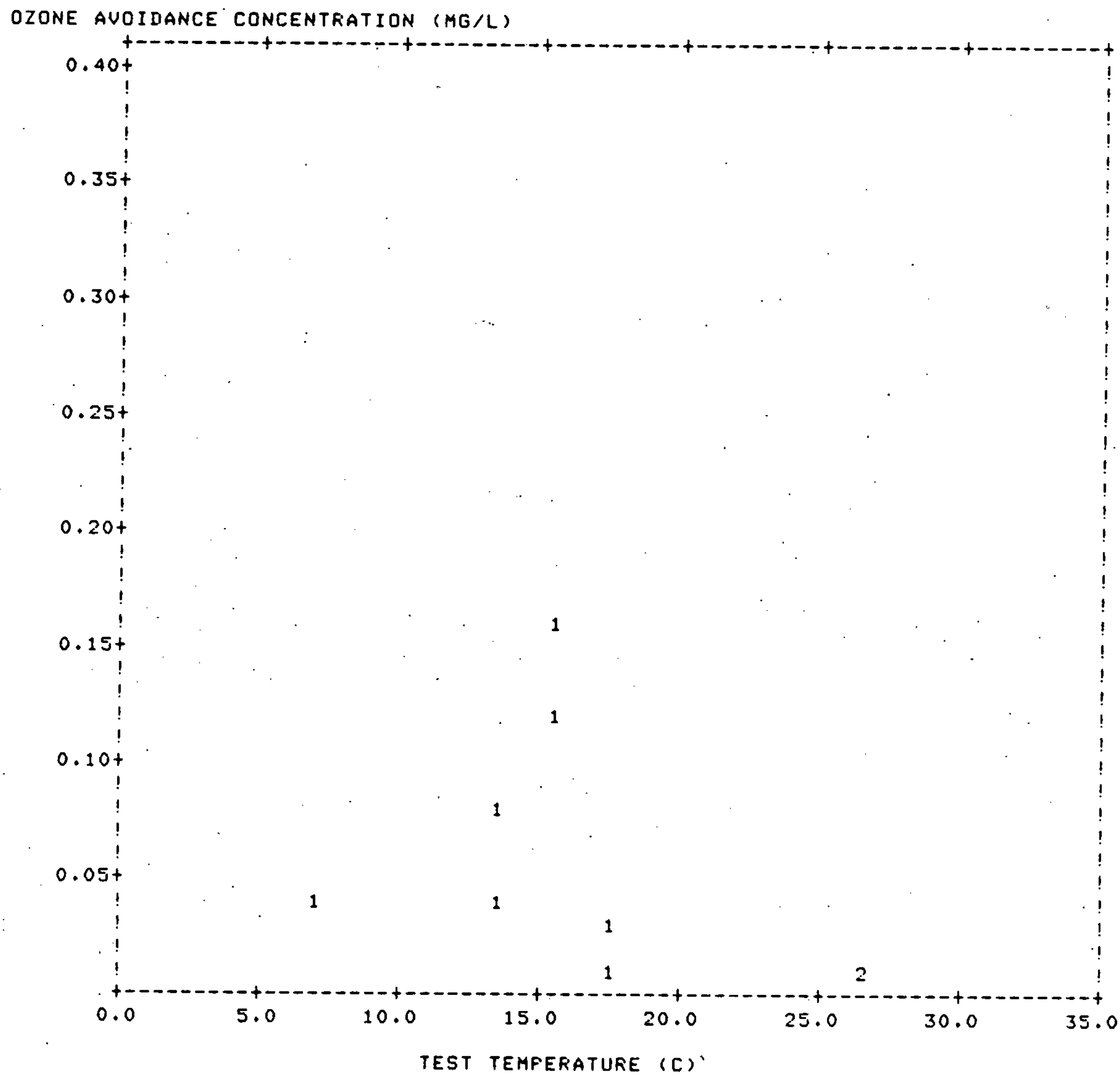


Figure 39. Ozone avoidance concentrations of blueback herring, *Alosa aestivalis*, vs. test temperatures at Mercer.

Notes:

1. The number of data points in indicated numberically.

2. Ozone is measured as chlorine.

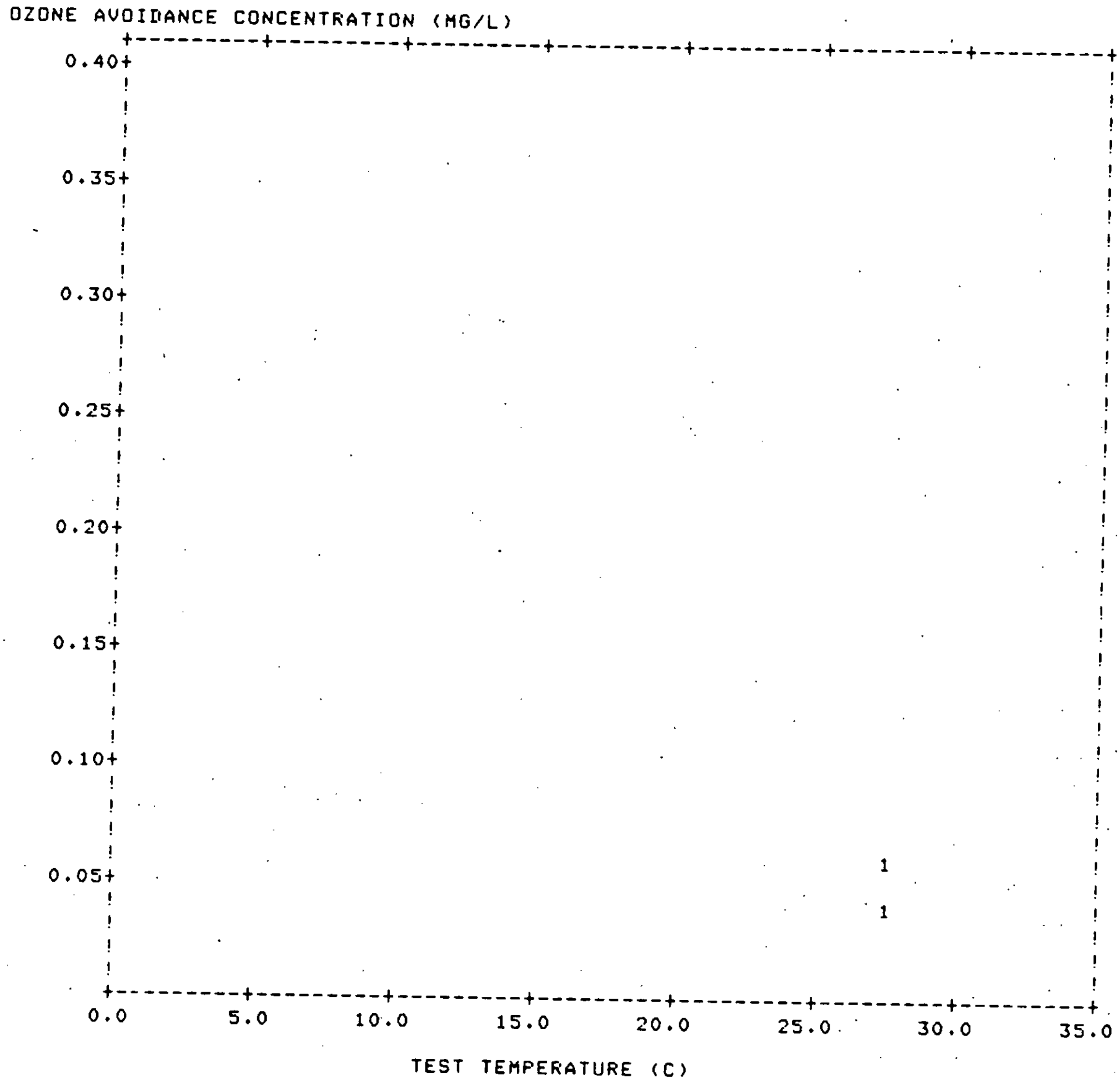


Figure 40. Ozone avoidance concentrations of alewife, *Alosa pseudoharengus*, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. Ozone is measured as chlorine.

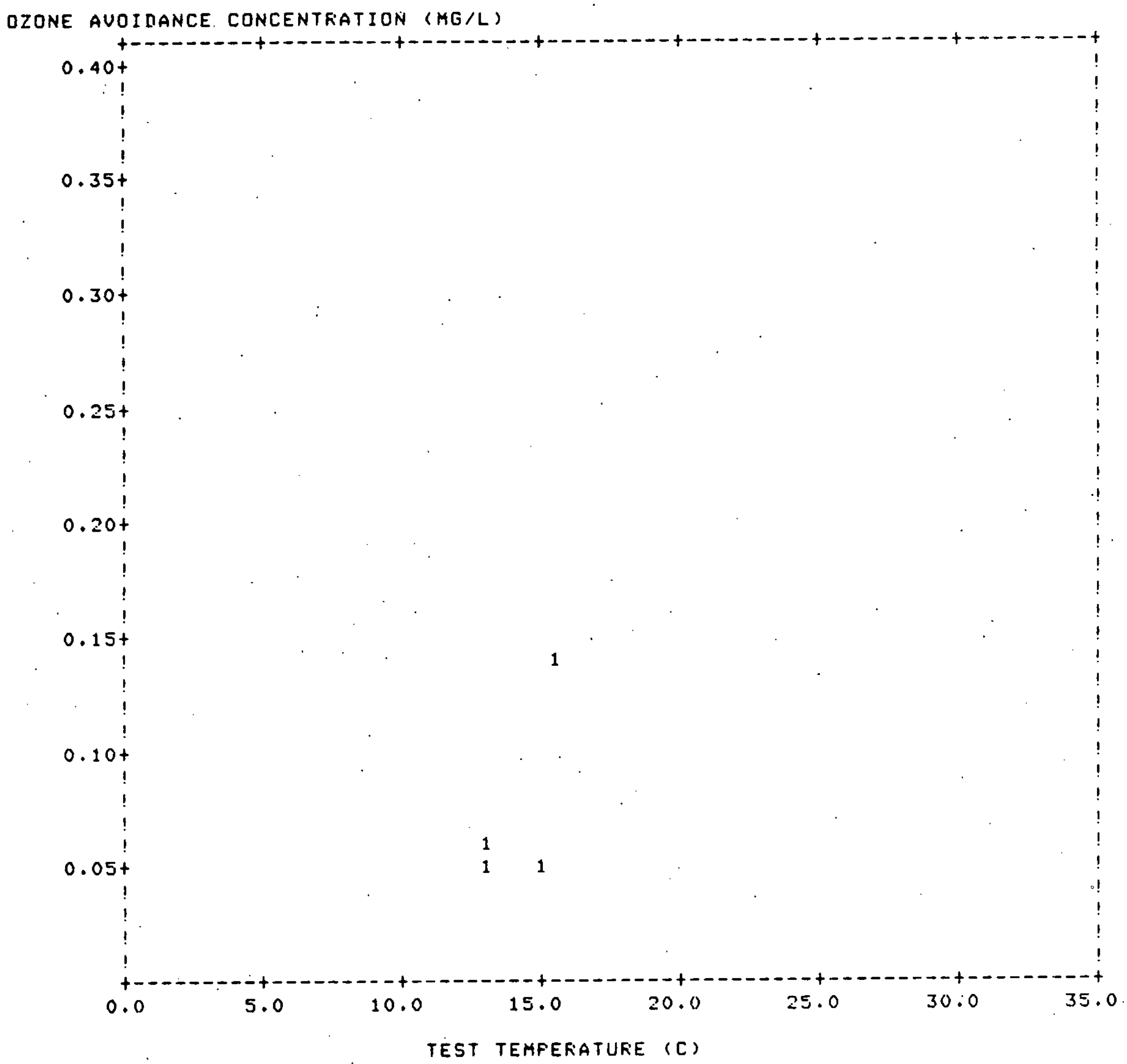


Figure 41. Ozone avoidance concentrations of rainbow trout, <u>Salmo gairdneri</u>, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically
2. Ozone is measured as chlorine.

Figure 42. Correlation analysis showed a highly significant ($P \leq 0.01$) inverse relationship between ozone avoidance concentration and test temperature.

Banded killifish were tested over a range of average conditions which extended from 5-7 C; 11.2-12.9 mg/l dissolved oxygen; and pH from 7.9-8.2. Avoidance concentrations extended from 0.10-0.36 mg/l ozone (measured as chlorine) with a mean of 0.19 mg/l and a standard deviation of 0.07. The highest test concentration failed to elicit avoidance in one test even though it exceeded the average avoidance concentration. The avoidance concentrations are plotted against their respective test temperatures in Figure 43.

White perch were tested over a range of average experimental temperatures from 6.8-25.8 C; levels of dissolved oxygen from 9.7-12.3 mg/l; and pH from 7.1-7.9. Avoidance concentrations extended from 0.06-0.24 mg/l ozone (measured as chlorine) with a mean of 0.16 mg/l and a standard deviation of 0.06. The avoidance concentrations are plotted against their respective test temperatures in Figure 44. Correlation analysis showed a significant ($P \leq 0.01$) inverse relationship between the ozone avoidance concentration and test temperature.

PHYSIOGRAPHIC ("COUGH" RESPONSE) STUDIES

Physiographic traces of "cough" responses were made at Bergen with mummichog and white perch exposed to chlorinated, ozonated, and ambient water. A summary of test conditions and "cough" rates observed and noted on the traces at Bergen is given in Table 13.

At Mercer, traces were made with rainbow trout, spottail shiner, banded killifish, and white perch exposed to chlorinated, ozonated, and ambient water. A summary of test conditions and "cough" rates observed and noted on traces at Mercer are given in Table 14.

"Coughs" (gill purges), "yawns" (perhaps another purging behavior), respiratory, and behavioral changes were evident with increases in biocide concentrations with all fishes tested. However, "coughs" remained the most quantitative measure in the study (<u>11</u>). Sprague (<u>12</u>)

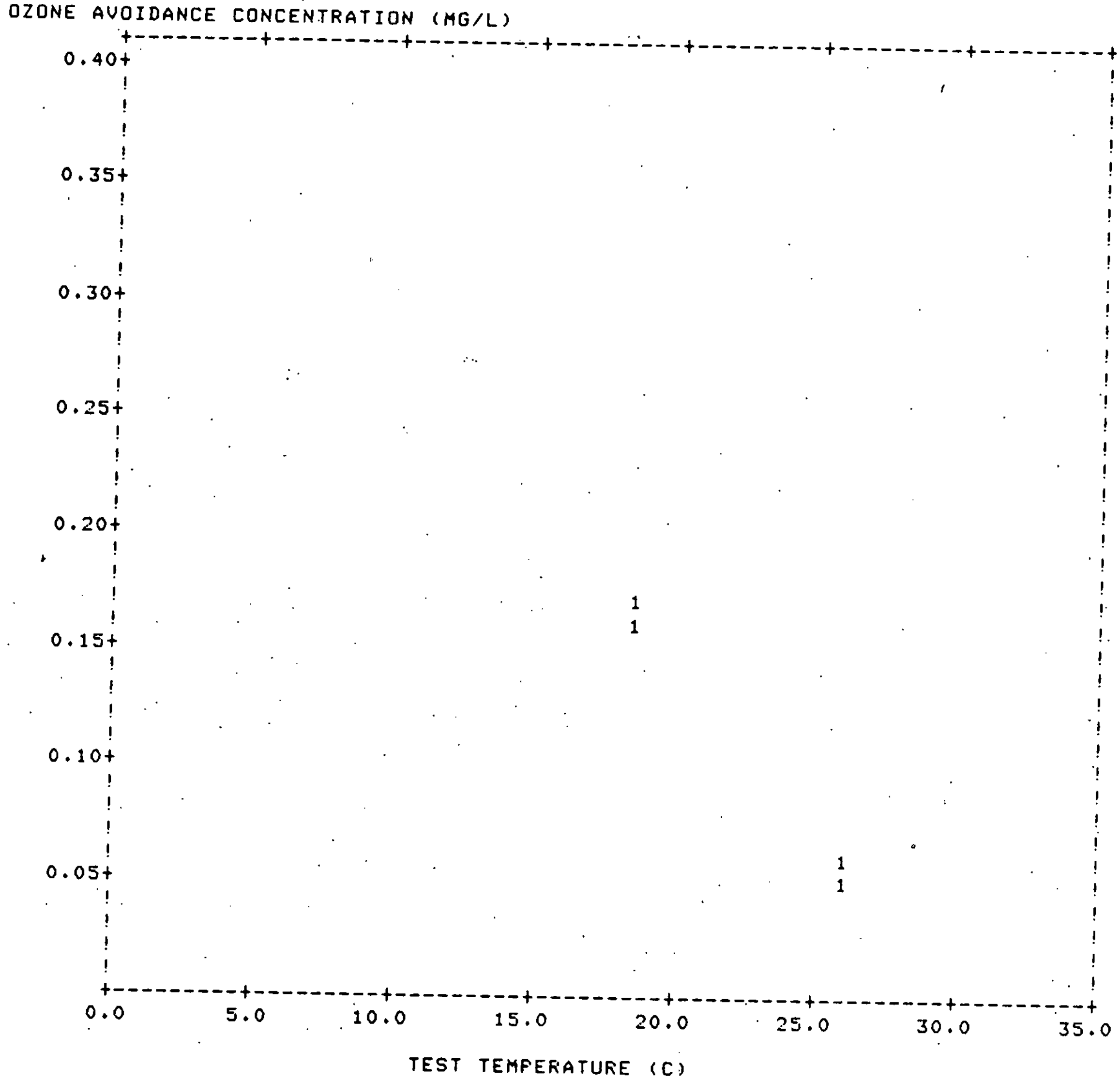


Figure 42. Ozone avoidance concentrations of spottail shiner, _Notropis hudsonius_, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Ozone is measured as chlorine.

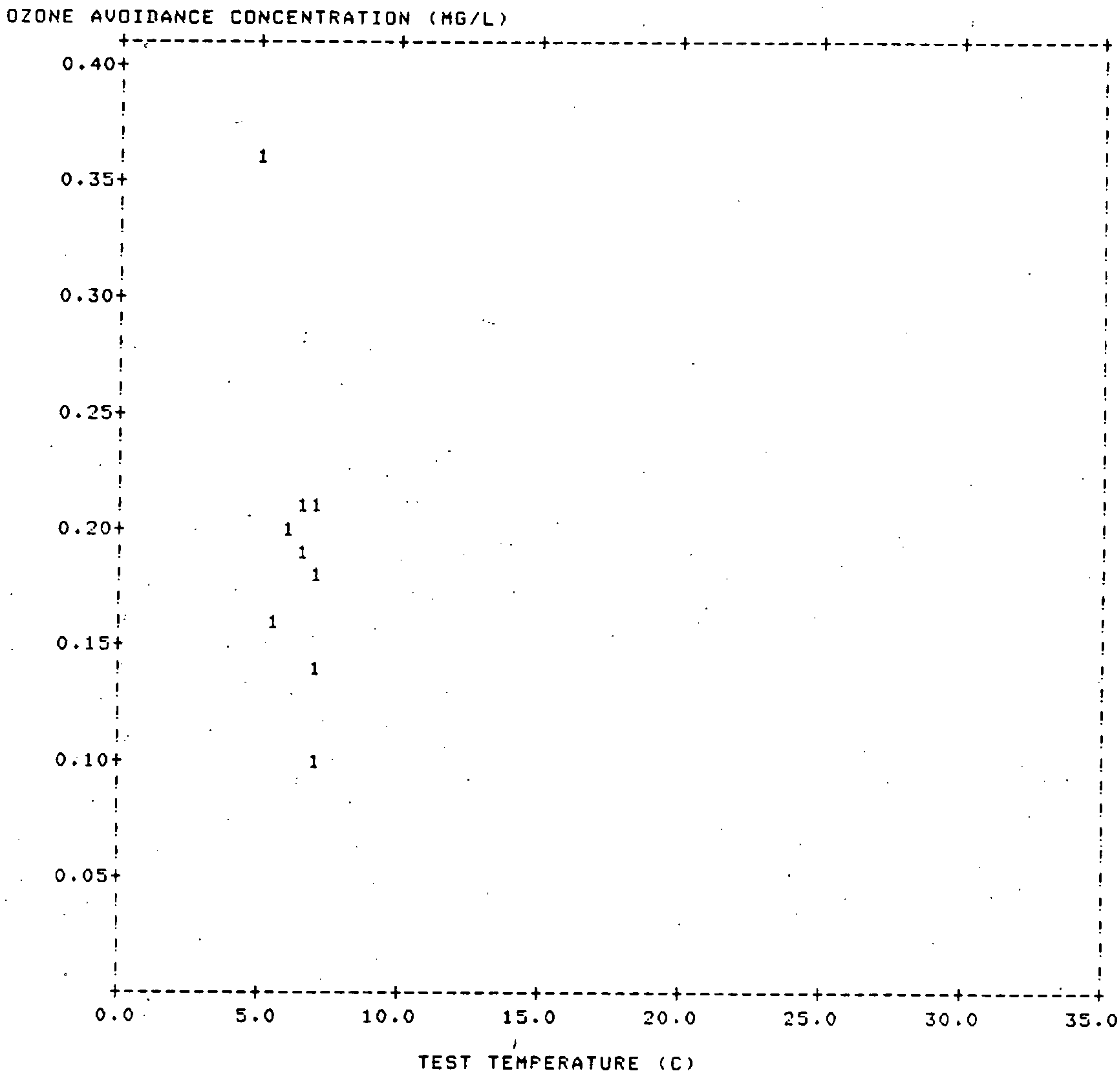


Figure 43. Ozone avoidance concentrations of banded killifish, Fundulus diaphanus, vs. test temperatures at Mercer.

Notes:

1. The number od data points is indicated numerically.

2. Ozone is measured as chlorine.

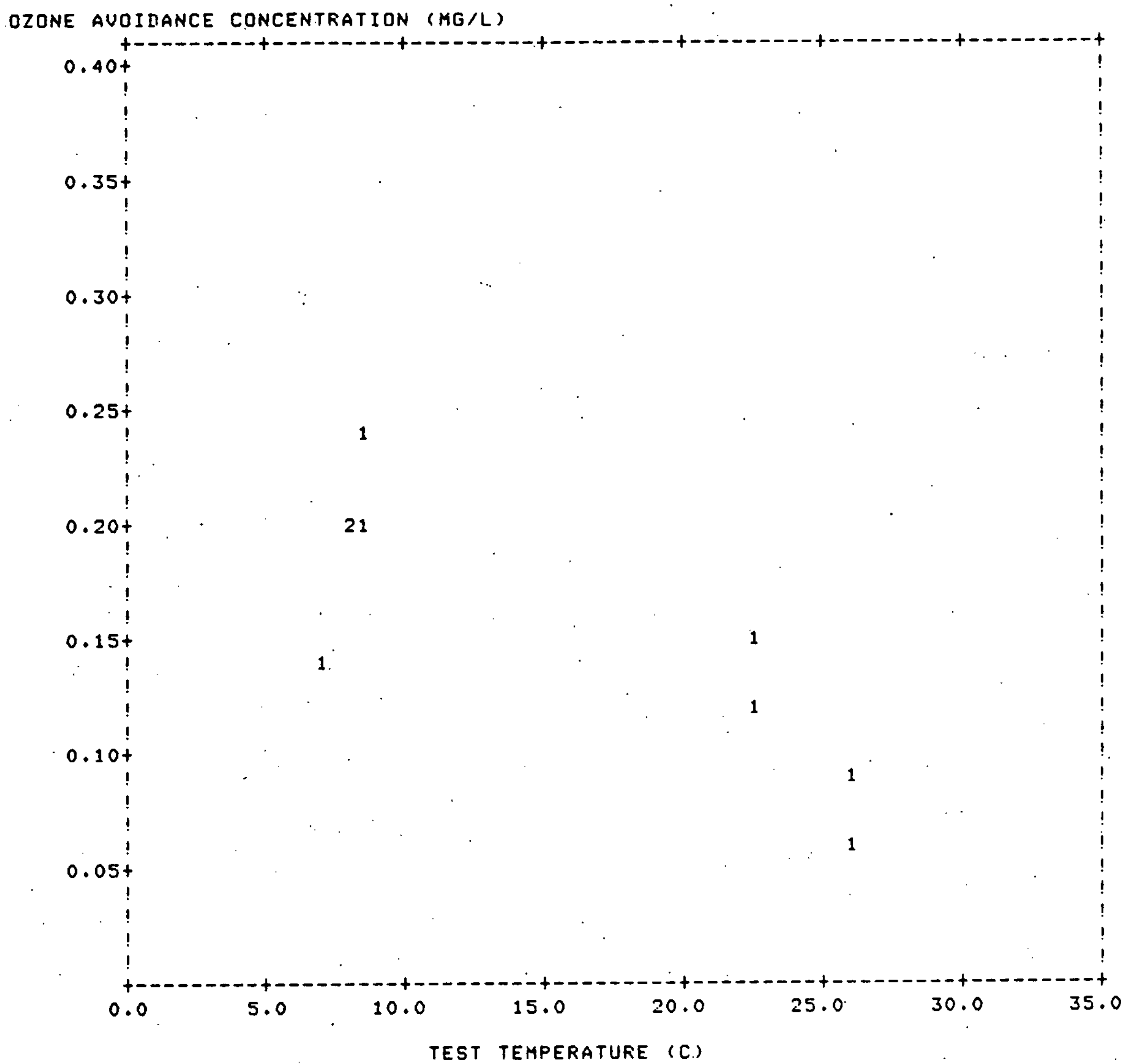


Figure 44. Ozone avoidance concentrations of white perch, Morone americana, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Ozone is measured as chlorine.

Table 13

A chronological summary of test conditions and "cough" rates observed and noted on physiographic traces of mummichog, <u>Fundulus heteroclitus</u>; and white perch, <u>Morone americana</u>; exposed to chlorinated (1) or ozonated (2) thermal discharges at Bergen.

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
FUNDULUS HETEROCLITUS							
23 FEB 79	2	6.7	1	0	15	3.8	0
				0.03	15	3.8	0.25
23 MAR 79	1	6.9	0.5	0	21	2.7	0
				0.05	21	2.7	0.38
				0.15	21	2.7	0.4
				0.15	21	2.7	0.08
23 MAR 79	2	6.9	0.5	0	21	2.7	0
				0.4	21	-	1
				1	21	-	1.5
				0.7	21	-	1.7
19 APR 79	1	7.1	1	0	23	5	0
				0.1	23	5	0.4
19 APR 79	2	7.1	1	0	23	5	0
				0.17	23	15.2	0
20 APR 79	1	7.3	1	0	21	4.3	0
				0.05	21	4.3	0
				0.12	21	4.3	0
20 APR 79	2	7.3	1	0	21	5.9	0
				0.17	22	11.2	0
				0.23	22	11.2	0
21 JUN 79	1	7.2	1.5	0	26	3	1
				0.01	27.5	3.6	1
				0.08	27.5	3.6	1.25
				0.1	29.5	3.6	1.5
				0.11	28	3.6	1.4
				0.13	30	3.6	1.85
				0.14	30	3.6	2
				0.15	30	3.6	9.4
				0.17	30.5	3.6	2.6
				0.18	30	3.6	4.8
				0.19	30	3.6	3.6

Table 13 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
FUNDULUS HETEROCLITUS							
22 JUN 79	2	7.3	1.5	0	26	4.1	0.21
				0	25.5	3	0.8
				0.01	27	-	0.83
				0.06	28	-	0.4
				0.11	28	-	0.6
				0.14	29	-	1
				0.22	30	-	0.4
				0.4	31.5	20	0.2
26 JUN 79	2	7.2	2.5	0	25.5	4.8	3
				0.08	27	-	0.8
				0.11	27.5	-	0.21
				0.18	28.5	-	1
				0.29	30.5	18.4	0.8
27 JUN 79	2	7.2	2.5	0	25.5	4.7	1
				0.25	31	20	0.2
				0.25	31	20	0.4
				0.3	31	20	0
				0.3	31	20	0.6
MORONE AMERICANA							
23 FEB 79	2	6.7	1	0	15	3.8	0.25
				0.03	15	3.8	2.5
17 MAY 79	1	7.2	2	0	24	4.5	1.8
				0.01	24	4.5	1.4
				0.02	24	4.5	7.2
				0.03	24	4.5	5.2
				0.04	24	4.5	4.2
				0.05	24	4.5	4.4
17 MAY 79	2	7.3	2	0	23.5	5.4	2.4
				0.04	23.5	-	2.2
				0.06	23.5	-	0.2
				0.11	23.5	11.4	1.4
22 JUN 79	2	7.2	1.5	0	25.5	3	12.6
				0.01	27	3	5.8
				0.06	28	-	3.4
				0.14	28	-	2.8
				0.15	29	-	2.6
				0.22	30	-	1.2
				0.38	31.5	20	1.6

Table 14

A chronological summary of test conditions and "cough" rates observed and noted on physiographic traces of rainbow trout, Salmo gairdneri; spottail shiner, Notropis hudsonius; banded killifish, Fundulus diaphanus; and white perch, Morone americana; exposed to chlorinated (1) or ozonated (2) waters at Mercer.

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
SALMO GAIRDNERI							
23 APR 80	1	7.8	0	0	14	9.4	2.4
				0.04	14	9.2	3
				0.12	14.5	9	10.4
				0.12	14.5	9	23
				0.18	15	8.7	10.4
				0.18	15	8.7	25.8
				0.25	15.5	8.6	21.6
				0.25	15.5	8.6	25.4
				0.35	17	8.3	39
				0.43	17	8.3	40
				0.48	17	8.2	42.8
				0.63	17.5	7.7	39
24 APR 80	2	7.8	0	0	15	9.1	0.4
				0.04	15	10	1
				0.05	15.5	10.4	0.8
				0.1	16	10.8	8.8
				0.1	16	10.8	14.2
				0.12	16	10.4	35.8
				0.3	16.5	10.9	44.2
				0.54	16.5	12.5	42.4
				0.76	16.5	13.2	39.4
NOTROPIS HUDSONIUS							
3 JAN 80	1	7.9	0	0	6.5	11.2	0.6
				0.06	-	-	0.6
				0.09	-	-	0.6
				0.11	-	-	0
				0.14	-	-	0.4
				0.2	-	-	1.8
				0.24	-	-	2
				0.32	-	-	3.2
				0.38	-	-	3.8
				0.43	6	11	1.7

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
NOTROPIS HUDSONIUS							
4 JAN 80	1	8.1	0	0	4.5	11.2	0.6
				0.04	-	-	0.6
				0.07	-	-	0.6
				0.05	-	-	1.4
				0.11	-	-	0.8
				0.13	-	-	1.2
				0.15	-	-	1.8
				0.23	-	-	2.6
				0.27	6	11	3
4 JAN 80	2	7.9	0	0	5.5	11	0
				0.02	-	-	0
				0.06	-	-	0
				0.41	5.5	14.2	1.6
29 JAN 80	2	8.1	0	0	4.5	11	0.4
				0.05	4.5	11.8	0.4
				0.1	4.5	12.6	0.2
				0.15	4.5	13	9.2
				0.15	4.5	13	7.6
				0.07	5	12.8	2.2
				0.2	5	12.8	2.2
				0.31	5	13	3
31 JAN 80	2	8.1	0	0	3	11.6	0.2
				0.01	3	12	0.4
				0.1	3	12.8	0
				0.16	5	13.3	9
				0.17	5	13.4	4.6
				0.37	4.5	13.8	2
15 MAY 80	2	7	0	0	18	6.8	0.8
				0.04	18.5	8.2	1.4
				0.11	19	9.5	0.8
				0.22	19	11.8	9.4

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
NOTROPIS HUDSONIUS							
16 MAY 80	1	7	0	0	18	7.3	0.4
				0.14	18	7.2	10.2
				0.24	18.5	7.1	12
				0.35	19	6.7	3
16 MAY 80	1	7	0	0	19	7.1	0.2
				0.03	19	7.8	1
				0.07	19	7.9	4.4
				0.1	19	7.9	12.4
				0.16	18.5	8.2	13.4
3 JUL 80	2	7.2	0	0	26	6.1	0
				0.02	26	11.7	0
				0.07	26	13	8.8
				0.22	26	14.2	0
FUNDULUS DIAPHANUS							
17 JAN 80	2	8	0	0	7.5	10.8	0
				0.06	8	11.4	0
				0.1	8	12	0
				0.21	7.5	12.4	3
				0.28	7	12.8	0
18 JAN 80	2	7.9	0	0	6.5	10.4	0
				0.04	6.5	11.2	0
				0.08	7	11.6	0
				0.16	7	12	0
				0.27	7.5	12.2	0
				0.36	8	12.2	0
				0.58	8	12.6	0.4
				0.79	7.5	12.8	0
				0.9	9	13.2	0.4

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
FUNDULUS DIAPHANUS							
23 JAN 80	2	8	0	0	6	10.8	0
				0.08	5.5	12.1	0.2
				0.14	6	12.2	0
				0.22	6.5	12.4	0
				0.3	6.5	12.5	0
				0.35	6.5	12.6	3
				0.4	6	13.1	0.8
				0.65	6	13.6	2.2
				0.65	7.5	13.8	1.6
24 JAN 80	1	8.1	0	0	3.5	11.4	0
				0.13	3.5	11.6	0
				0.14	3	12.2	0
				0.16	3	12.4	0
				0.29	3	12.7	0
				0.29	3	13	0.8
				0.53	3	13	0.6
				0.43	3	13.1	0.8
				0.66	3	13.6	0.2
				0.84	3	13.7	0.6
13 MAR 80	1	7.9	0	0	6	11	0
				0.23	6	11	0
				0.37	6	11.2	0.4
				0.67	6.5	11.2	0.2
				0.73	6.5	11.2	1.2
				0.86	6.5	11	1.6
				0.97	6.5	11	0.8
				1.02	6	11	0.6
				1.21	6	11	0
				1.59	6	11.1	0.2
				1.93	6	11.1	0.2
				2.21	6.5	11	1
14 MAR 80	2	7.9	0	0	5	10.8	0.2
				0.01	5	11.4	0
				0.04	5	12.2	0.2
				0.1	5.5	13	0.2
				0.17	5.5	13.3	12.8
				0.34	5.5	13.8	1
				0.44	5	14.2	0.2
				0.74	5	14.5	0

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
MORONE AMERICANA							
26 DEC 79	2	7.7	0	0	8.5	10.2	0.6
				0.04	-	-	0.4
				0.08	-	-	0.8
				0.1	-	-	0.6
				0.13	-	-	0.8
				0.14	8	11.9	0.6
27 DEC 79	1	7.8	0	0	6.5	11.1	0.4
				0.08	-	-	0
				0.15	-	-	1
				0.18	-	-	1
				0.25	-	-	1.6
				0.28	-	-	1
				0.35	-	-	1.2
				0.39	-	-	1.4
				0.42	-	-	1.4
				0.57	-	-	1.4
				0.62	-	-	1.7
				0.98	8.5	10.3	1.6
28 DEC 79	2	7.8	0	0	6	10.3	0.8
				0.04	-	-	1.4
				0.07	-	-	1.6
				0.1	7	12.1	1.6
27 FEB 80	2	8.2	0	0	7	11.4	0.6
				0.05	7.5	12.4	0.8
				0.11	7.5	13.3	1.4
				0.25	8	14.1	6.4
				0.36	8	14.5	3.2
				0.55	8	14.7	3.6
				1.05	5.5	14.8	3.6
				0.97	4.5	14	2.8
28 FEB 80	1	7.7	0	0	4.5	11.3	0
				0.07	4.5	11.4	0.4
				0.12	5	11.5	0.8
				0.19	5	11.6	3
				0.25	5	11.6	1
				0.31	5.5	11.6	0.6
				0.4	5.5	11.6	1
				0.65	5.5	11.6	0.8
				0.9	5	11.6	0.8
				1.27	5	11.6	0.8

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
MORONE AMERICANA							
20 MAR 80	1	7.9	0	0	7	10.2	0.6
				0.07	7.5	10.2	0.4
				0.14	8	10.2	0.8
				0.22	8.5	10.2	2.2
				0.28	9	10.1	1.6
				0.33	8.5	10.3	2.2
				0.38	8.5	10.4	1
				0.43	8.5	10.6	2.6
				0.53	8.5	10.6	1.4
				0.62	8	10.6	0.8
				0.69	8	10.6	2.8
				0.88	8	10.6	1.2
21 MAR 80	2	7.9	0	0	7.5	10.2	0.4
				0.03	9	11.5	0.6
				0.05	9	11.8	0.2
				0.07	9	12.4	0.4
				0.11	9	13	0.4
				0.14	9	13.4	0
				0.19	9	13.2	0
				0.29	9	13.4	0.2
				0.32	9	13.7	0.4
				0.46	9	14.2	0.2
				0.64	9	14.2	1.2
2 APR 80	2	7.6	0	0	8	10.4	0.8
				0.06	9	11.2	0.4
				0.13	9.5	11.6	0.6
				0.23	9.5	12	0.4
				0.23	9.5	12.6	3.4
				0.28	9.5	13.2	0.6
				0.45	9.5	14	1.4
				0.58	10	13.6	2.8
				0.7	10	13.8	1.7
				0.8	9.5	14.2	2
				1.02	9.5	14.6	2.8

Table 14 (continued)

DATE	BIOCIDE	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
MORONE AMERICANA							
3 APR 80	1	7.6	0	0	10	10.4	1.2
				0.09	10	10.4	2.6
				0.12	10.5	10.3	6.8
				0.15	11	10.2	2.4
				0.18	11	10.2	1.6
				0.24	11	10.2	3.4
				0.33	11	10.4	3
				0.46	10.5	10.5	1.2
				0.55	10.5	10.6	3.2
				0.6	10.5	10.6	3.2
				0.75	10.5	10.6	1.4
				0.92	10.5	10.6	3
27 MAY 80	1	7.2	0	0	20.5	8.3	0.4
				0.03	21	8.5	3.6
				0.04	21.5	8.5	1.4
				0.05	21.5	8.5	3.4
				0.1	22	8.5	4.4
				0.15	22	8.4	8.4
				0.23	22	8.4	7.4
				0.34	22	8.4	14.2
				0.48	21.5	8.5	13.6
16 JUN 80	2	7.3	0	0	23	7.2	0.4
				0.03	22	9.7	0.8
				0.08	22	10.6	1.2
				0.14	22	11.4	15.4
				0.22	23.5	14.4	23.4
				0.28	24	15.2	17.6
				0.44	24.5	16	15.8
				0.57	24	17.5	13.4
17 JUN 80	1	7.5	0	0	22	7.1	0.4
				0.05	22.5	7.1	1.8
				0.1	22.5	7.3	1.6
				0.15	23	7.1	2.8
				0.19	24	7.1	4.2
				0.28	23	7.6	8.6
18 JUN 80	1	8.4	0	0	23.5	8.8	0.6
				0.05	23.5	7.8	2.2
				0.1	23.5	7.6	3.6
				0.18	24	7.8	3.8
				0.25	24.5	8.5	5.4
				0.31	24.5	7.9	19.4
				0.41	24.5	8.4	20.8
				0.5	24.5	8	14.4
				0.67	24	7.8	13.6

reported that respiratory impairment in fish was a good indicator of toxicant stress, but that the rate of "coughing" showed more promise than opercular rate as a meaningful response to sublethal concentrations.

There were differences in the intensity of "coughs" as well as the pattern of responses between fishes tested. White perch had large, distinct "coughs" with increasing biocide concentrations. Conversely, spottail shiner had very small "coughs" which resembled a "stutter", possibly resulting from rapid opercular movement. Only rainbow trout exhibited a continually increasing "cough" rate with increasing biocide concentrations. All other fishes had a peak in "cough" rate followed by a gradual or rapid decline in "coughs".

The concentration which produced an initial "cough" response was chosen as the physiologically detected concentration. The initial "cough" response was defined as an increase of at least one "cough" per minute (during an exposure period) over the "cough" rate prior to exposure. An increase of less than one "cough" per minute was considered within the range of a normal "cough" response.

Although determination of the initial "cough" response was the major objective of this study, physiographic traces were conducted at concentrations beyond this initial level to those which elicited avoidance and occasionally to toxic levels.

Chlorine Physiographic Studies

Bergen. A summary of the total chlorine concentrations which elicited an initial "cough" response with mummichog and white perch at Bergen is given in Table 15. Avoidance concentrations which occurred in concurrent avoidance tests are also presented.

Tests with mummichog were conducted over a range of experimental conditions extending from 21.0-30.5 C; 2.7-5.0 mg/l dissolved oxygen; 0.5-1.5 ppt salinity; and pH from 6.9-7.3. The highest concentration tested at 21 C (0.15 mg/l) and at 23 C (0.10 mg/l) failed to elicit an initial "cough" response. At an average test temperature of 29 C mummichog exhibited an initial "cough" response at 0.14 mg/l total

Table 15

A summary of total chlorine concentrations which elicited an initial "cough" response in physiographic tests and an avoidance response in concurrent avoidance tests with mummichog, Fundulus heteroclitus; and white perch, Morone americana; at Bergen. (*=highest test concentration did not elicit an initial "cough" response)

Date	Test Temp (C)	Initial Cough Response Conc. Total Cl_2 (mg/l)	Concurrent Avoid. Conc. Total Cl_2 (mg/l)
Fundulus heteroclitus			
23 Mar 79	21	0.15*	-
19 Apr 79	23	0.10*	-
20 Apr 79	21	0.12*	-
21 Jun 79	29	0.14*	0.12 0.15
Morone americana			
17 May 79	24	0.02	0.02 0.03

chlorine. This was within the range of avoidance concentrations (0.12-0.15 mg/l) observed in concurrent avoidance tests.

White perch tested at 24 C; 4.5 mg/l dissolved oxygen; 2 ppt salinity; and a pH of 7.2 exhibited an initial "cough" response at 0.02 mg/l total chlorine. This was similar to the avoidance concentrations (0.02 an 0.03 mg/l) observed in concurrent avoidance tests.

Mercer. A summary of the total chlorine concentrations which elicited an initial "cough" response with rainbow trout, spottail shiner, banded killifish, and white perch is given in Table 16. Also presented are avoidance concentrations which were obtained in concurrent avoidance tests.

Rainbow trout tested at an average experimental temperature of 15.5 C exhibited an initial "cough" response at 0.12 mg/l total chlorine. In concurrent tests, a concentration of 0.18 mg/l total chlorine was avoided by rainbow trout.

Spottail shiner was tested over a range of average test conditions which extended from 5.5-19 C; 7.1-11.1 mg/l dissolved oxygen; and pH from 7.0-8.1. Initial "cough" response concentrations extended from 0.07-0.20 mg/l total chlorine with a mean of 0.14 mg/l and a standard deviation of 0.05. The initial "cough" response concentrations and their respective average test temperatures are plotted for spottail shiner in Figure 45. Although not significant ($P \leq 0.05$), there appears to be an inverse correlation ($r=0.75$, 2 d.f.) between temperature and the concentration which elicited an initial "cough" response. The initial "cough" response concentration (0.07 mg/l) for spottail shiner tested at 19 C was lower than the avoidance concentrations (0.10 and 0.11 mg/l) exhibited in concurrent tests.

Banded killifish were tested at average experimental temperatures of 3 and 6 C; respective levels of dissolved oxygen of 12.7 and 11.1 mg/l; and a respective pH of 8.1 and 7.9. An initial "cough" response occurred at 0.73 mg/l total chlorine for banded killifish tested at 6 C. However, at 3 C no initial "cough" response was exhibited at concentrations up to 0.84 mg/l total chlorine (the highest concentration tested). Banded killifish exhibited an ability to acclimate

Table 16

A summary of total chlorine concentrations which elicited an initial "cough" response in physiographic tests and an avoidance response in concurrent avoidance tests with rainbow trout, Salmo gairdneri; spottail shiner, Notropis hudsonius; banded killifish, Fundulus diaphanus; and white perch, Morone americana; at Mercer. (*=the highest test concentration did not elicit an initial "cough" response)

Date	Test Temp (C)	Initial Cough Response Conc. Total Cl_2 (mg/1)	Concurrent Avoid. Conc. Total Cl_2 (mg/1)
Salmo gairdneri			
23 Apr 80	15.5	0.12	0.18 0.18
Notropis hudsonius			
3 Jan 80	6.5	0.20	- -
4 Jan 80	5.5	0.15	- -
16 May 80	18.5	0.14	- -
16 May 80	19	0.07	0.10 0.11
Fundulus diaphanus			
24 Jan 80	3	0.84*	2.00 2.05
13 Mar 80	6	0.73	2.17 1.60
Morone americana			
27 Dec 79	7.5	0.25	0.10 0.10
28 Feb 80	5	0.19	- -
20 Mar 80	8	0.22	0.25 0.31
3 Apr 80	10.5	0.09	0.17 0.10

Table 16 (continued)

Date	Test Temp (C)	Initial Cough Response Conc. Total Cl_2 (mg/l)	Concurrent Avoid. Conc. Total Cl_2 (mg/l)
27 May 80	21.5	0.03	0.21 0.15
17 Jun 80	23	0.05	- -
18 Jun 80	24	0.05	0.23 0.36

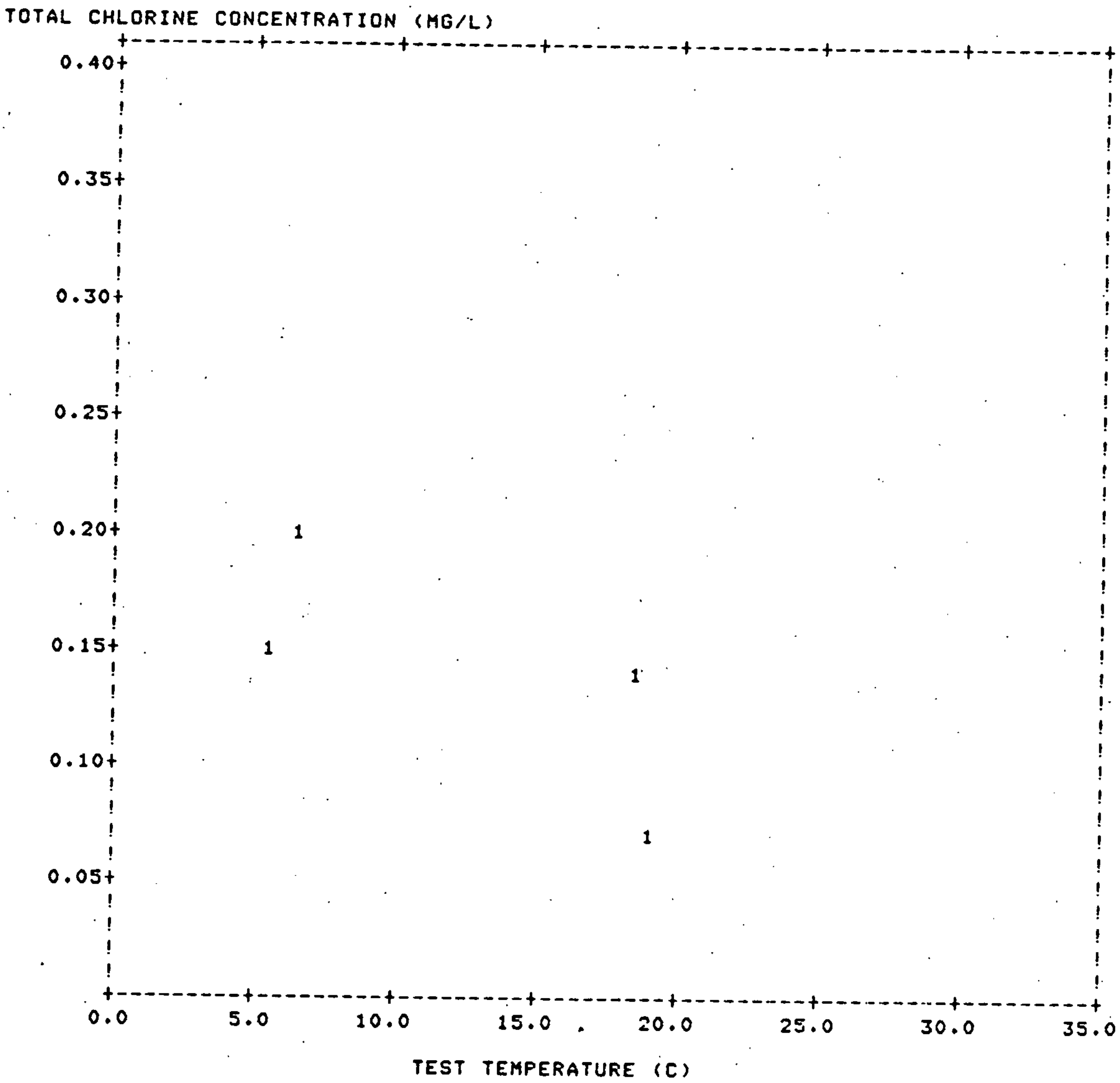


Figure 45. Total chlorine concentrations which elicited an initial "cough" response with spottail shiner, Notropis hudsonius, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

to an increase in chlorine; "coughing" for 5-10 minutes and then reverting back to a normal "cough" rate. Concurrent avoidance concentrations (1.60-2.17 mg/l) for banded killifish were much greater than the initial "cough" response concentrations.

A series of physiographic traces were taken with white perch over a range of average conditions which extended from 5-24 C; 7.2-11.6 mg/l dissolved oxygen; and pH of 7.2-8.4. Initial "cough" response concentrations extended from 0.03-0.25 mg/l total chlorine with a mean of 0.13 mg/l and a standard deviation of 0.09. The initial "cough" response concentrations and their respective average test temperatures are plotted for white perch in Figure 46. Test temperature was significantly ($P \leq 0.01$) inversely correlated ($r=-0.88$ 5 d.f.) with initial "cough" response concentration. Except for the concurrent avoidance test at 7.5 C, avoidance concentrations were greater than initial "cough" response concentrations. The difference between avoidance and initial "cough" concentrations became greater as the test temperature increased.

Ozone Physiographic Studies

Bergen. A summary of the ozone (measured as chlorine) concentrations which elicited an initial "cough" response with mummichog and white perch at Bergen is given in Table 17. Also presented are avoidance concentrations which resulted from avoidance tests conducted in conjunction with the physiographic tests.

Mummichog were tested over a range of average conditions which extended from 15-30 C; 2.7-17 mg/l dissolved oxygen; 0.5-2.5 ppt salinity; and pH from 6.7-7.3. At 21 C, there was an initial "cough" response at 0.40 mg/l ozone (measured as chlorine). However, no initial "cough" response was observed in any of the other tests conducted at 15-23 C. Tests conducted at or above 28 C resulted in a decreased cough rate with increasing ozone. Similarly, no avoidance concentrations were found with mummichog subjected to ozone residuals (measured as chlorine) up to 0.42 mg/l in concurrent avoidance tests.

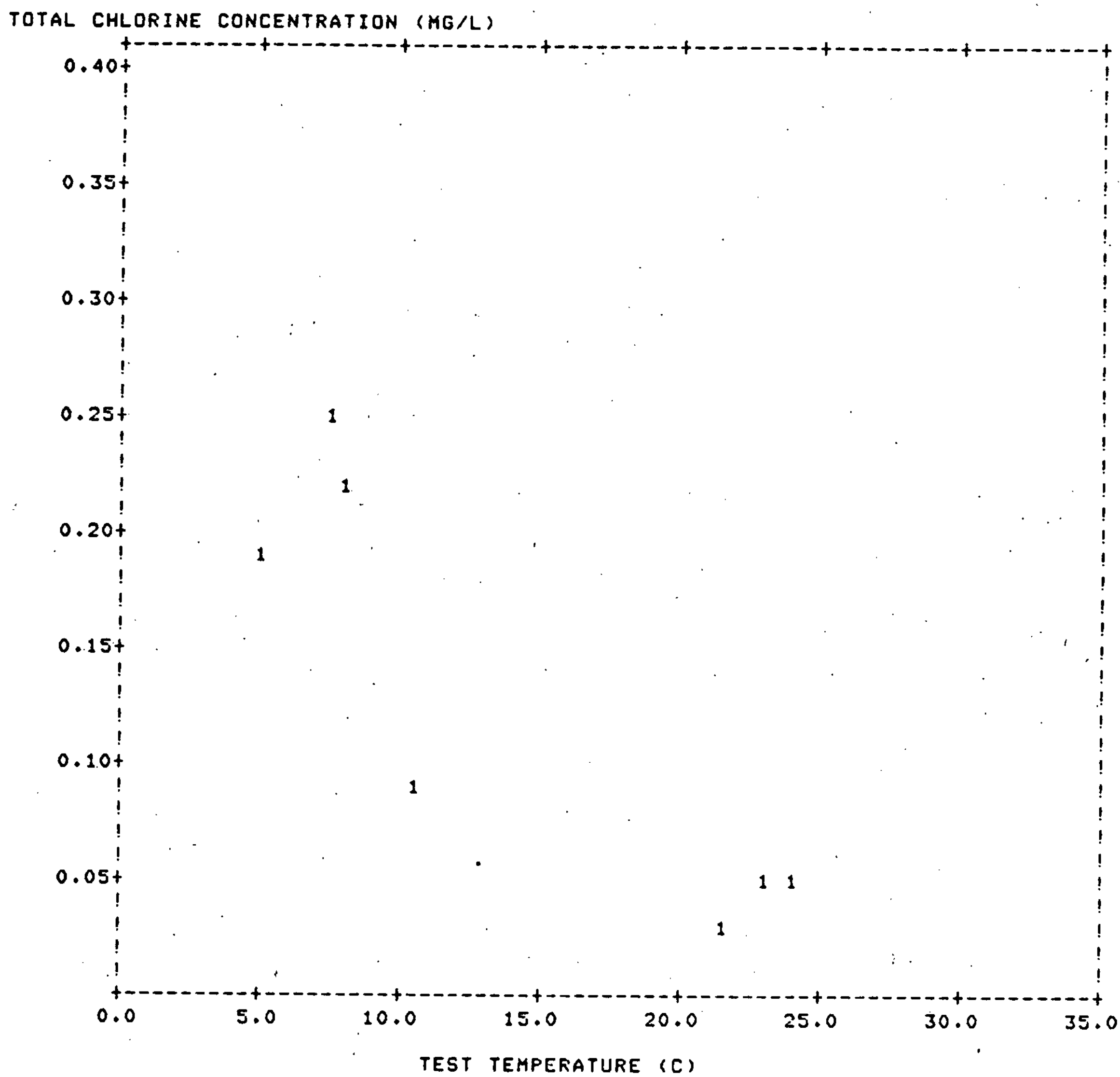


Figure 46. Total chlorine concentrations which elicited an initial "cough" response with white perch, *Morone americana*, vs. test temperatures at Mercer.

Note: The number of data points is indicated numerically.

Table 17

A summary of ozone (measured as chlorine) concentrations which elicited an initial "cough" response in physiographic tests and an avoidance response in concurrent avoidance tests with mummichog, *Fundulus heteroclitus*; and white perch, *Morone americana*; at Bergen. (*=highest test concentration did not elicit an initial "cough" response; **=highest test concentration did not elicit an avoidance response)

Date	Test Temp (C)	Initial Cough Response Conc. O_3 (mg/l)	Concurrent Avoid. Conc. O_3 (mg/l)
Fundulus heteroclitus			
23 Feb 79	15	0.03*	- -
23 Mar 79	21	0.40	- -
19 Apr 79	23	0.17*	- -
20 Apr 79	22	0.23*	- -
22 Jun 79	28	0.40*	0.42** 0.42**
26 Jun 79	28	0.29*	0.29** 0.22
27 Jun 79	30	0.30*	0.36** 0.36**
Morone americana			
23 Feb 79	15	0.03	- -
17 May 79	23.5	0.11*	0.10** 0.06
22 Jun 79	28.5	0.38*	- -

White perch were tested over a range of average conditions which extended from 15-28.5 C; 3.8-8.5 mg/l dissolved oxygen; 1-2 ppt salinity; and pH from 6.7-7.3. Although white perch exhibited an initial "cough" response when exposed to 0.03 mg/l ozone (measured as chlorine) at 15 C, "cough" rate decreased with increasing ozone residuals at 23.5-28.5 C and no initial response could be determined. In concurrent avoidance tests conducted at 23.5 C, white perch avoided 0.06 mg/l ozone (measured as chlorine) but in the replicate did not avoid 0.10 mg/l (the highest concentration tested).

Mercer. A summary of ozone (measured as chlorine) concentrations which elicited an initial "cough" response with rainbow trout, spottail shiner, banded killifish, and white perch is given in Table 18. Also presented are avoidance concentrations which resulted from avoidance tests conducted in conjunction with the physiographic tests.

Rainbow trout exhibited an initial "cough" response at 0.10 mg/l ozone (measured as chlorine) under conditions which averaged 16 C; 10.9 mg/l dissolved oxygen; and pH 7.8. Concurrent avoidance concentrations for rainbow trout were 0.05 and 0.14 mg/l ozone (measured as chlorine).

Traces were conducted with spottail shiner over a range of average conditions which extended from 4-26 C; 9.1-12.8 mg/l dissolved oxygen; and pH from 7-8.1. Initial "cough" response concentrations extended from 0.07-0.22 mg/l ozone (measured as chlorine) with a mean of 0.15 mg/l and a standard deviation of 0.06. Initial "cough" response concentrations and their respective test temperatures are plotted for spottail shiner in Figure 47. No significant ($P \leq 0.05$) relationship was found between temperature and initial response concentrations. Avoidance concentrations were slightly lower than initial "cough" response concentrations in concurrent tests.

Table 18

A summary of ozone (measured as chlorine) concentrations which elicited an initial "cough" response in physiographic tests and an avoidance response in concurrent avoidance tests with rainbow trout, Salmo gairdneri; spottail shiner, Notropis hudsonius; banded killifish, Fundulus diaphanus; and white perch, Morone americana; at Mercer. (*=the highest test concentration did not elicit an initial "cough" response)

Date	Test Temp (C)	Initial Cough Response Conc. O_3 (mg/l)	Concurrent Avoid. Conc. O_3 (mg/l)
Salmo gairdneri			
24 Apr 80	16	0.10	0.14 0.05
Notropis hudsonius			
29 Jan 80	4.5	0.15	- -
31 Jan 80	4	0.16	- -
15 May 80	18.5	0.22	0.17 0.16
3 July 80	26	0.07	0.05 0.06
Fundulus diaphanus			
17 Jan 80	7.5	0.21	0.21 0.19
18 Jan 80	7.5	0.90*	0.21 0.18
23 Jan 80	6.5	0.35	- -
14 Mar 80	5	0.17	0.36 0.16
Morone americana			
26 Dec 79	8.5	0.14*	- -
28 Dec 79	6.5	0.10*	0.14 -
27 Feb 80	7	0.25	- -

Table 18 (continued)

Date	Test Temp (C)	Initial Cough Response Conc. O_3 (mg/l)	Concurrent Avoid. Conc. O_3 (mg/l)
21 Mar 80	9	0.64*	0.20 0.20
2 Apr 80	9.5	0.23	0.20 0.24
16 Jun 80	23	0.14	0.12 0.15

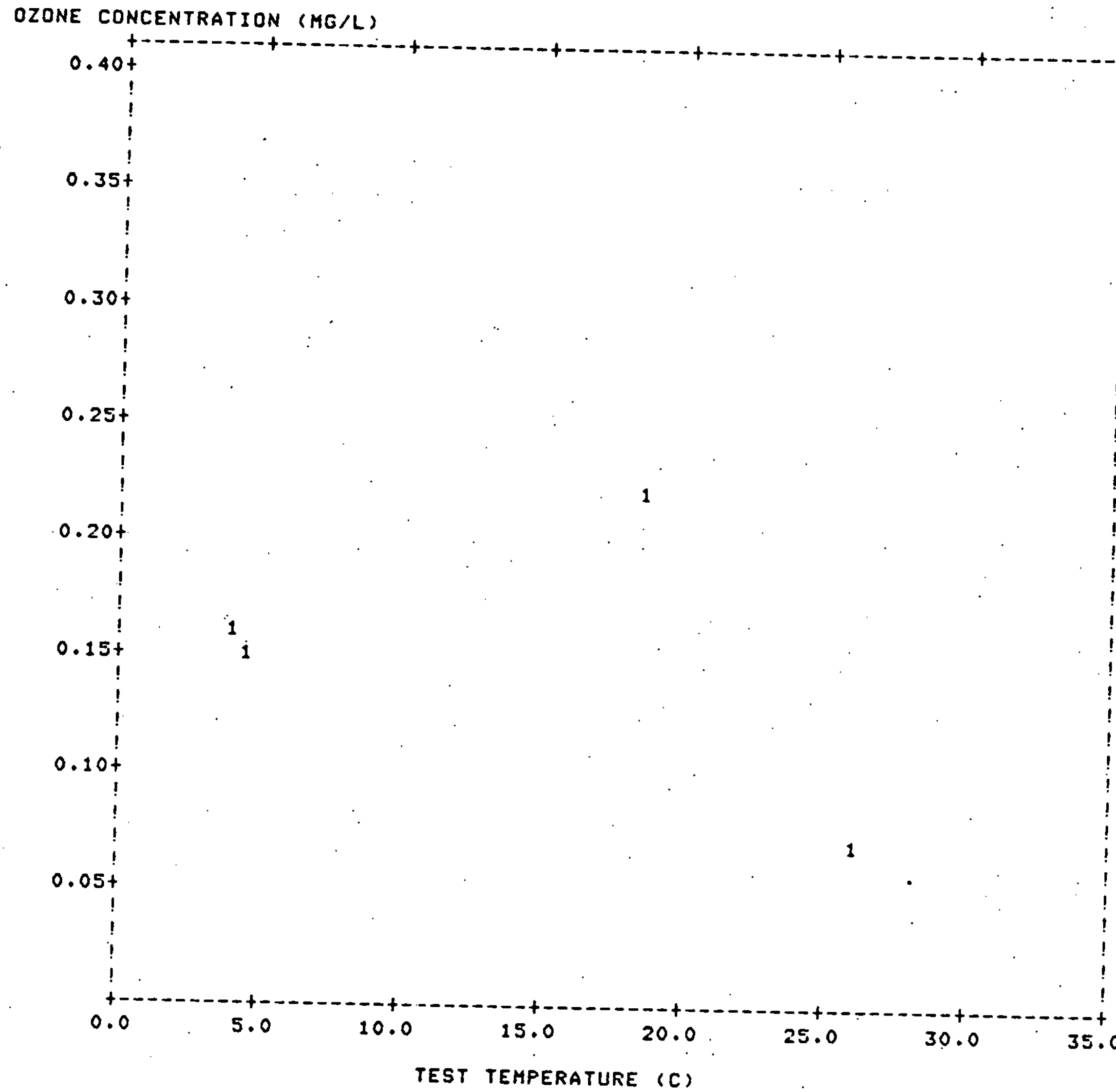


Figure 47. Ozone concentrations which elicited an initial "cough" response with spottail shiner, <u>Notropis hudsonius</u>, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically.
2. Ozone is measured as chlorine.

Banded killifish were tested at average experimental temperatures from 5-7.5 C; levels of dissolved oxygen from 11.9-12.9 mg/l; and pH from 7.9-8.0. Initial "cough" response concentrations extended from 0.17-0.35 mg/l ozone (measured as chlorine) with a mean of 0.24 mg/l and a standard deviation of 0.09. One test resulted in no response when exposed to concentrations up to 0.90 mg/l ozone (measured as chlorine, the highest concentration tested). As in the chlorine tests, banded killifish appeared to acclimate to an increase in ozone after 5-10 minutes. Avoidance concentrations (0.16-0.36 mg/l ozone, measured as chlorine) occurring in concurrent tests were in about the same range as the initial "cough" response concentrations, although the mean avoidance concentration (0.22 mg/l) and standard deviation (0.07) were slightly, but not significantly ($P \leq 0.05$), lower.

White perch were tested at a series of average conditions which extended from 6.5-23 C; 11.1-13.7 mg/l dissolved oxygen; and pH from 7.3-8.2. Initial "cough" response concentrations were from 0.14-0.25 mg/l ozone (measured as chlorine) with a mean of 0.21 mg/l and a standard deviation of 0.06. Three tests resulted in no initial "cough" response even though the mean concentration was exceeded in one such test. Initial "cough" response concentrations and their respective average test temperatures are plotted for white perch in Figure 48. There was a significant ($P \leq 0.01$) inverse correlation (r=-1.00, 1 d.f.) between temperature and the concentration of ozone which elicited an initial "cough" response in white perch. However, the number of data points (3) is extremely limited and more data should be obtained to confirm the correlation. In tests in which an initial "cough" response was observed and a concurrent avoidance test was conducted, the initial "cough" response concentration was within the range of avoidance concentrations.

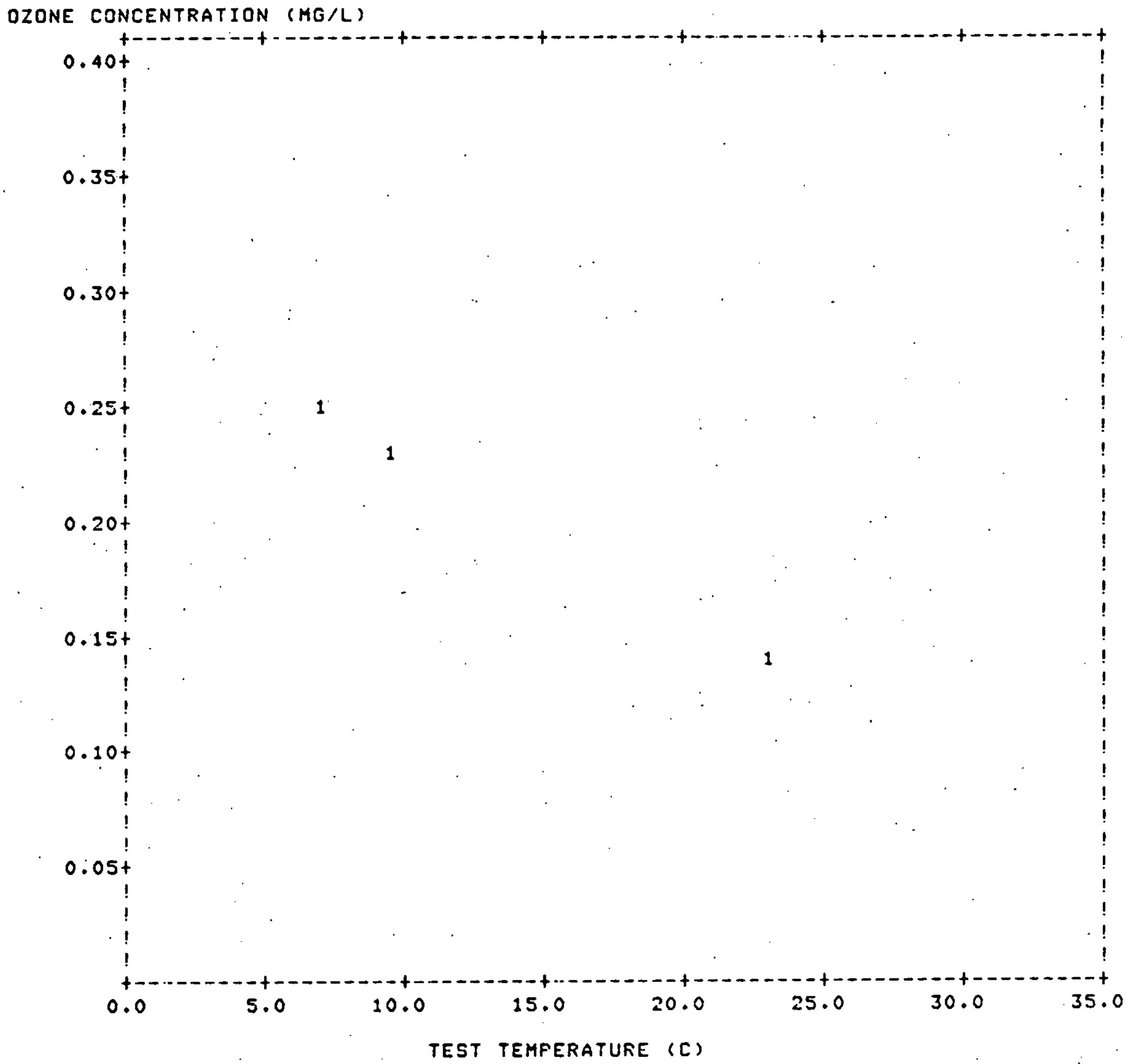


Figure 48. Ozone concentrations which elicited an initial "cough" response with white perch, Morone americana, vs. test temperatures at Mercer.

Notes:

1. The number of data points is indicated numerically.

2. Ozone is measured as chlorine.

Section 4

CONCLUSIONS

The results of tests evaluating the lethal effects of chlorine and ozone on mummichog and white perch at Bergen indicate the biological effects of ozone were less severe than those of chlorine. Conversely, the results of toxicity tests at Mercer on alewife, spottail shiner, rainbow trout, and white perch indicate the biological effects of chlorine were less severe than those of ozone.

At Bergen, the $ILC_{50(96,2)}$'s for chlorine with mummichog and white perch were about 0.54 mg/l and 0.10 mg/l, respectively. Contrastingly, levels of 1 mg/l ozone (measured as chlorine) failed to cause any mortality with mummichog or white perch. At Mercer, the $ILC_{50(96,2)}$'s for spottail shiner, rainbow trout, and white perch exposed to chlorine were higher than those for ozone. The $ILC_{50(96,2)}$ for alewife exposed to chlorine was 0.27 mg/l but exposure to ozone resulted in 100% mortality at all concentrations tested (0.15-0.86 mg/l ozone; measured as chlorine) in 2 hours.

The relative effects of ozone and chlorine in the behavioral studies were consistent with those observed in the toxicity studies. At Bergen, the avoidance concentrations of mummichog averaged 0.09 mg/l total chlorine but those for ozone (measured as chlorine) exceeded 0.42 mg/l. White perch avoided an average 0.10 mg/l ozone (measured as chlorine) but accepted no more than an average 0.04 mg/l total chlorine. At Mercer, the average chlorine avoidance concentrations were higher than the average ozone avoidance concentrations for blueback herring, alewife, rainbow trout, spottail shiner, banded killifish, and white perch. As expected, all avoidance concentrations observed at Mercer and Bergen were less than lethal levels.

Initial "cough" response concentrations at Bergen for mummichog and white perch were lower when exposed to chlorine than when exposed to ozone. At Mercer, rainbow trout and banded killifish exhibited lower initial "cough" response concentrations when exposed to ozone than when exposed to chlorine. Spottail shiner exhibited about the same cough response sensitivity to chlorine and to ozone. However, white perch exhibited a lower initial "cough" rate when exposed to chlorine than when exposed to ozone.

In general, the initial "cough" response concentrations elicited at Bergen and Mercer were either about the same or only slightly less than avoidance concentrations in concurrent physiograph-avoidance tests. Spottail shiner exposed to chlorine exhibited a slightly lower avoidance concentration when compared with the concentration which elicited an initial "cough" response.

The differences in the biological effects of chlorination and ozonation at Bergen and Mercer are best evaluated using the results obtained with white perch, the only organism tested at both stations. Unfortunately, comparisons are limited because more tests were conducted over a wider temperature range at Mercer than at Bergen. White perch were less tolerant of, and more sensitive, to chlorine at Bergen than at Mercer. Conversely, they were less tolerant of, and more sensitive to, ozone at Mercer than at Bergen. This difference may largely be due to differences in the chemistry of chlorine and ozone in estuarine and fresh waters. Oxidative by-products resulting from chlorination and ozonation depend upon the oxidizable components in the aquatic system. As these components vary significantly between estuarine and fresh waters it is to be expected that the by-products, and hence, the biological effects of ozone and chlorine will be site specific. In fact, white perch were not subjected to ozone at Bergen but to an unknown by-product of ozonation. The effects of chlorination and ozonation were undoubtedly further affected by the despoiled water at Bergen.

Although not statistically significant ($P \leq 0.05$), there appears to be an inverse relationship between temperature and the lethal effect for white perch exposed to chlorine and to ozone; and for spottail shiner exposed to ozone. More tests are needed over a wide range of temperatures for each fish to confirm the relationship.

The concentration which produces a physiological effect also appears to be inversely related to temperature for white perch exposed to ozone and to chlorine; and for spottail shiner exposed to chlorine. A similar inverse relationship between temperature and ozone avoidance concentrations also exists for blueback herring, spottail shiner, and white perch. Conversely, spottail shiner avoided higher concentrations of total chlorine as temperature increased.

The effect of a 2-3 C ΔT accompanying the biocide concentration was evaluated in several avoidance tests. Mummichog and white perch tested at Bergen avoided similar chlorine concentrations in both ambient temperature and ΔT (0.5-2.0 C) tests. No comparative ΔT tests were conducted at Bergen using ozone.

Blueback herring was the only fish tested with a ΔT accompanying the test concentration at Mercer. Although limited, the results show blueback herring avoided higher ozone concentrations when a 2-3 C ΔT accompanied the test concentration. When exposed to a 0.5 C ΔT accompanying chlorine, blueback herring avoided similar concentrations in both ΔT and ambient temperature tests. However, in one replicate ΔT test, blueback herring preferred chlorine concentrations beyond the mean avoidance concentration.

Evidence of gill damage on fish tested at Mercer was rare. Some aneurisms and hemorrhaging were noted in both experimental and control fish. Considerably more aneruisms and hemorrhaging were noted on the gills of fish tested at Bergen. However, gill damage was observed in both experimental and control groups at Bergen and was likely attributable to the poor quality of the dilution water.

The results of these studies can be compared with those obtained at other laboratories. The biological effects of any oxidizing biocide on a given species, however, are highly dependent on the time of exposure and usually are site specific. Some difference in results at different locations is due to laboratory and test population differences but most can be attributed to differences in quality of dilution water. This is especially true for tests conducted in water of different salinity.

In chlorine toxicity tests with white perch the $ILC_{50(96,2)}$ was 0.10 mg/l total chlorine at Bergen and an average 0.73 mg/l total chlorine at Mercer. The mean 96-hour LC_{50} for white perch continuously exposed to chlorine proportionally diluted with water from the Delaware River estuary was 0.22 mg/l total chlorine; standard deviation was 0.08 (13). It is probable that an intermittent chlorine exposure to white perch using the higher salinity water (up to 7 ppt) of the Delaware River estuary would result in an $ILC_{50(96,2)}$ exceeding the 0.22 mg/l $LC_{50(96)}$. However, whether it would approach the $ILC_{50(96,2)}$ at Mercer is unknown. The chlorine avoidance concentrations of white perch tested at Bergen and Mercer averaged 0.04 and 0.20 mg/l respectively; whereas the average total chlorine avoidance concentration of white perch in Delaware estuarine waters was 0.06 mg/l (14).

The $ILC_{50(96,2)}$ for rainbow trout at 5 C (at Mercer) was 0.48 mg/l ozone (measured as chlorine). Contrastingly, Wedemeyer, et al (15) reported a continuous exposure 96-hour LC_{50} averaging 0.01 mg/l ozone (measured as chlorine) for rainbow trout at 10 C. Rosenlund (15), studying the use of ozone for a hatchery system, observed gill epithelial damage and death of rainbow trout exposed to 0.01-0.06 mg/l ozone at a temperature of 10-14 C. However, Rosenlund determined 90% of the ozone concentrations using a semiquantitative orthotolidine method. Ward and DeGraeve (17) observed no mortality at 15 C with rainbow trout when exposed continuously to a nondisinfected effluent from a wastewater treatment plant ozonated to 0.01 mg/l for 48 hours. Although the residuals were determined amperometrically, they did not report whether the ozone residual was measured as chlorine or as ozone. Considering the confusion in the literature regarding the determination of ozone and the fact that none of these other studies used intermittent exposures, comparisons are extremely difficult. It is clear, however, that the toxicity of ozone is less in intermittent exposures than in continuous exposures.

The $ILC_{50(96,2)}$ value for rainbow trout exposed to chlorine in this study (0.67 mg/l total chlorine) was between continuous exposure values and those obtained in other studies in which rainbow trout were exposed to chlorine intermittently for less than 2 hr. Merkens (18) reported a 7-day LC_{50} value of 0.08 mg/l for rainbow trout. Basch, et al (19) reported 4-day LC_{50} values of 0.14-0.29 mg/l for rainbow trout. Brooks and Seegert (20) reported that the 30-minute LC_{50} and three-5-minute exposure (with 3 hours between each 5 minute exposure) LC_{50} for rainbow trout acclimated at 10 C were 0.99 and 2.87 mg/l, respectively.

Because of the time dependent nature of the toxicity of these biocides it would seem appropriate to base water quality criteria on site-specific sub-lethal effects rather than on toxicity data. As initially hypothesized, lethal concentrations of biocides were detected and avoided. Although the physiologically detected levels were slightly lower than avoidance concentrations, it is likely that irritating levels would eventually be avoided in longer exposure tests. Consequently, if their use is intermittent, the most likely environmental impact resulting from the use of these biocides in electric generating stations would be temporary loss of habitat. When used in despoiled waters, ozone would probably even be beneficial.

This study represents our initial attempts to define the ecological effects of ozonation when used for condenser biofouling control at electric generating stations. Obviously much more work needs to be done, but the results reported here are encouraging enough to warrant further investigation.

Section 5

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