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

A Report on the Studies Conducted
at the PSE&G Bergen Generating Station
February-June 1979
for Public Service Electric and Gas
and U.S. Department of Energy

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by

John W. Meldrim, Ph.D.
Technical Director, Experimental Studies
Ichthyological Associates, Inc.
Middletown, Delaware
and
Ernest R. Holmstrom and George E. Balog
Ichthyological Associates, Inc.
PSE&G Bergen Generating Station
Ridgefield, New Jersey

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Ichthyological Associates, Inc.
Edward C. Raney, Ph.D., President
301 Forest Drive, Ithaca, New York 48105

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Introduction

Biofouling accumulation can reduce the heat transfer across condenser tube walls and severely lower power plant thermal efficiency and fuel utilization. The power industry prevents this accumulation by injecting biocides in the condenser inlet water. Presently, chlorine is the most popular biocide used, however, its impact on the aquatic environment has led to the search for other alternatives. Public Service Electric and Gas Company has proven that ozone can be used to prevent biofouling accumulation and is now determining the optimum dose of chlorine and of ozone using a system of model condensers. In conjunction with this study the effects of the ozonated and chlorinated thermal discharges of these condensers are being evaluated. This report covers the biological evaluation conducted at the PSE&G Bergen Generating Station (February-June 1979).

Laboratory Description

The Biological Evaluation Laboratory is a 12 x 46 ft mobile trailer (Fig. 1) located at the Bergen Generating Station adjacent to Overpeck Creek, a tributary of the Hackensack River. It consists of three rooms. An office is located in the front room. The holding facility and physiographic system are located in the back room. The middle room contains two toxicity systems and two modified Shelford-Allee avoidance systems. The Laboratory is located adjacent to the Water Quality Laboratory which houses the model condenser system. Discharge water from each of three test condensers (untreated, chlorinated, and ozonated) is

pipled to the Laboratory for experimental studies. Separate pipes for each water condition enter the Laboratory in the back room and then run to the front of the middle room. Untreated condenser water can also be added to either the chlorinated or ozonated condenser water near the point of intake.

The holding facility is a flowing water closed-cycle system which consists of three 50-gallon (190 liter) oval holding tanks and an 88-gallon (333 liter) delivery tank. The delivery tank supplies dechlorinated city water to the holding tanks and is equipped with heaters and a refrigeration unit for temperature control. Water in the delivery tank is sterilized with a UV sterilizer, aerated, and filtered. Water is changed or replenished whenever necessary. The holding facility is maintained at ambient light levels under natural photoperiod. Due to the paucity of specimens in Overpeck Creek 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 Bergen Laboratory in insulated holding vessels. However, some test organisms were taken from Overpeck Creek and other sites in New Jersey.

Objectives

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

The objective of the acute (96 hour) toxicity study is to

determine the respective lethal levels (LC_{50}) of chlorinated and ozonated waters. The objective of the behavioral (avoidance) response study is to determine what (if any) concentrations of ozone and of chlorine will be avoided. The objective of the physiographic ("cough") response study is to determine what concentrations of ozone and of chlorine will elicit gill purges ("coughs"). Ozonated and chlorinated waters are to be evaluated in all studies for both the addition of increased temperature and without it.

Testing Procedures

Toxicity Studies

The toxicity testing system consists of two 4 x 8 ft tanks each containing twelve 10-gallon (39 liters) testing chambers and a water bath. Each tank is constructed of 3/4 inch exterior plywood and coated with inert epoxy resin. Nylon mesh baskets are suspended in each testing chamber to test invertebrates. Test concentrations are delivered to test chambers by mixing untreated water with treated water via pipes tapped into the intake system.

In February toxicity testing was conducted using flow-through exposure to chlorinated and 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 various concentrations of chlorinated and ozonated water. Aeration was not provided. Several concentrations of ozone and chlorine were used. Controls were maintained in untreated water. However, because of poor water quality and low levels of dissolved oxygen,

the results were unsatisfactory. Modifications in testing procedure were then implemented to improve survival.

The test condition between exposure periods 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. Test concentrations were produced by mixing untreated condenser water with chlorinated or ozonated water in the desired proportion. During the 2 hour exposure period the test was conducted in a continuous flow-through mode and aeration was supplied to the ozone control and chlorine chambers. (Aeration of the ozonated water was not necessary.) At the conclusion of the exposure period the flows were stopped and all test chambers were returned to the aerated static condition.

In the February test and in one test in March a flow rate of 0.15 liter per minute was used in each test chamber. However, clogging problems necessitated changing this to 0.3 liters per minute in the remaining tests. No toxicity tests were conducted after March due to the low concentrations of ozone and chlorine employed in the model condenser study.

Ozone and chlorine were measured using a Wallace and Tiernan Series A-790 amperometric titrator and expressed as total oxidant. The test concentration was the average concentration of one to four measurements taken during the exposure period.

Observations were made periodically. Time of loss of equilibrium and death (defined as cessation of opercular activity and lack of response to prodding with a glass rod) were recorded

for periods up to 96 hours. Dead organisms were measured, weighed, and preserved by freezing. Gill tissue was examined with a stereoscopic microscope. At the end of a test the remaining (live) organisms were measured, weighed, examined, and preserved.

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 are evaluated in an avoidance system consisting of two modified Shelford-Allee avoidance apparatuses (Meldrim, et al. 1974). Each apparatus is made of 3/4 inch exterior plywood and coated with inert epoxy resin. Each apparatus is 2 x 6 ft and is subdivided into 1 x 6 ft sub-troughs. The system is enclosed in black plastic for light control and to permit movement outside the system. The Duro-Test "Vita-Lite" is used for lighting. Each apparatus has a dose box which is divided into two compartments. One side receives untreated water from the intake system. The other side receives untreated and treated water from the intake system to produce a desired concentration. Water from each side of the dose box flows to diagonally opposite ends of the sub-troughs and then drains in the center. Due to a sharp gradient at the center drains each apparatus is "divided" into quadrants. Concentrations are produced by adjusting flowmeters and the flow into each sub-trough is regulated by flowmeter. Organisms are exposed to successively increased concentrations of each oxidant in a "step-gradient" fashion and their responses observed. At the beginning of a test equal numbers of test

organisms are 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) is determined for a duration of five minutes and a frequency distribution of organism-times is formed. The distribution is then subjected to statistical analysis to determine the significance of the response to the oxidant. A test continues until a significant avoidance response ($P = 0.05$ level) with a 2:1 ratio of time in control: time in treated water, or death is exhibited. Water temperature, dissolved oxygen, pH, and salinity are measured before and at the end of each test. Organisms are measured, weighed, and examined at the end of each test.

Physiographic ("Cough") Response Studies

The physiographic study system consists of four testing chambers and a four channel Narco physiograph. The chambers may receive a continuous flow of untreated water, chlorinated water, or ozonated water. Usually at least two chambers are used; one with untreated water and one with a biocide. All water is taken from the previously described avoidance system dose boxes. Stainless steel wire mesh electrodes are placed at each end of each chamber, the electrodes are then connected to the physiograph which records respiratory responses of test organisms. The chambers are placed in a three sided compartment with the fourth side covered with black plastic having small observation slits. In May screen barriers were placed in front of the electrodes to keep fish from coming into direct contact with the electrode. However, the barriers were subsequently removed because they

distorted the physiographic traces. In June a one-way mirror was added to the system to facilitate observations.

One fish is placed in each test chamber and supplied with a continuous flow of untreated water for at least 48 hours. During this time the fish are allowed to acclimate to the test chamber and establish a normal respiratory pattern. Periodic physiographic traces are made during this time and just prior to the exposure period to determine the degree of acclimation to the chamber. If the respiratory pattern is reasonably stable traces are then taken at each of several biocide concentrations (usually simultaneously with an untreated "control") for at least a five minute period. Exposure to a concentration is from 5 to 30 minutes before a trace is taken. Water temperature, dissolved oxygen, pH, and salinity are measured at the beginning and end of each test. Test organisms are measured, weighed, and examined at the end of each test.

Results and Discussion

Toxicity Studies

Acute (96-hr) toxicity tests of chlorine and ozone were conducted during February with mummichog, Fundulus heteroclitus, using the continuous flow-through condition. In the chlorine test (Table 1) the control group experienced 70% mortality, identical to that in the highest chlorine concentration (0.04 mg/l). The mortality in the control group in the ozone test (Table 2) 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 the surface "gulping air" and shortly thereafter lost equilibrium. Based on these tests the procedure was modified as described in the section on test procedures.

Toxicity testing in subsequent weeks was directed at determining which species could be tested (using the modified procedure) under the conditions of adverse water quality found at Bergen. Species subsequently tested for suitability included: blueback herring, Alosa aestivalis; mummichog, Fundulus heteroclitus; silvery minnow, Hybognathus nuchalis; white perch, Morone americana; and grass shrimp, Palaemonetes pugio. All except blueback herring were deemed suitable for testing.

Acute toxicity studies of chlorine and ozone were conducted during March using the modified procedure with mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio. Spottail shiner, Notropis hudsonius and silvery minnow, Hybognathus nuchalis were also tested but exposed only to ozonated water. As noted, no toxicity tests were conducted after March.

Results of tests on mummichog, tidewater silverside, white perch, and grass shrimp with chlorine during March 1979 are given in Table 3. Concentrations of total chlorine below 0.40 mg/l did not result in mortalities with mummichog but 100% mortality resulted at 0.08 mg/l with tidewater silverside and at 0.37 mg/l with white perch. A concentration of 0.12 mg/l resulted in over 50% mortality with white perch. However, concentrations of 0.37 mg/l resulted in 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. Percent mortality at 96 hours at each respective test concentration of total chlorine is plotted for mummichog in Figure 2 and for white perch in Figure 3. The 96 hour LC_{50} for a 2 hour intermittent exposure ($ILC_{50(96,2)}$) for mummichog is about 0.54 mg/l total chlorine but is only about 0.1 mg/l total chlorine for white perch.

Results of tests on silvery minnow, spottail shiner, mummichog, tidewater silverside, white perch, and grass shrimp with ozonated water are given in Table 4. Although ozone concentrations (as total oxidant) of 0.93 mg/l resulted in 50% mortality with silvery minnow and 100% mortality with spottail shiner, levels of 1.0 mg/l did not cause any mortality with mummichog and only 10% mortality with grass shrimp and only 20% mortality with tidewater silverside. A concentration of 0.97 mg/l did not cause mortality in 48 hours with silvery minnow and only 10% mortality with spottail shiner. No 96 hour ILC_{50} concentrations could be calculated because no test concentration of ozone resulted in more than 40% mortality in any 96 hour test.

Avoidance Response Studies

A series of behavioral avoidance responses to the chlorinated and ozonated thermal discharges were determined with mummichog and white perch from April through June 1979. Responses of mummichog to the chlorinated thermal discharge are summarized in Table 5. Tests were conducted over a range of conditions which averaged from 22-28.8 C in experimental temperature; 3.5-6.3 mg/l dissolved oxygen; 0.2-1.4 ppt salinity and 7.2-7.4

pH. Avoidance concentrations 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. The number of data points was insufficient for further statistical analysis. The highest available test concentration failed to elicit avoidance in three tests even though the average avoidance concentration was exceeded in one such test. To illustrate the variability the avoidance concentrations are plotted against their respective test temperatures in Figure 4.

Responses of white perch to the chlorinated thermal discharge are summarized in Table 6. Tests were conducted over a range of averaged experimental temperatures which extended from 22.5-28 C; 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 0.01-0.20 mg/l total chlorine with a mean avoidance concentration of 0.04 mg/l. However, the standard deviation (0.05) is greater than the mean. If the 18 May 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. Preliminary regression analyses (not presented) indicated that none of the test conditions significantly (P.05) affected the avoidance concentration in these tests. The number of data points was insufficient for further statistical analysis. The avoidance concentrations are plotted for their respective test temperatures in Figure 5.

Responses of mummichog to the ozonated thermal discharge are summarized in Table 7. Tests were conducted at averaged experimental temperatures extending from 26-28.5 C; levels of dissolved oxygen

from 6.5 to greater than 20 mg/l; salinity from 1.4-2.5 ppt; and pH from 7.2-7.3. In all except one test (avoidance concentration = 0.22 mg/l total oxidant) 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.

Responses of white perch to the ozonated thermal discharge are summarized in Table 8. Tests were conducted at averaged experimental temperatures extending from 20-27 C; levels of dissolved oxygen from 6.7-11.8 mg/l; salinity from 1-2.5 ppt; and pH from 7.3-7.6. The avoidance concentrations extended from 0.04-0.30 mg/l total oxidant with a mean of 0.10 mg/l ozone (as total oxidant) 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 further statistical analysis. Several ozone avoidance tests were attempted in June 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 6.

Physiographic ("Cough" Response) Study

Series of physiographic traces were made periodically throughout the study (February-June 1979) on mummichog and white perch exposed to the chlorinated and ozonated thermal discharges. Respective traces, shown in Figures 7-65, are both qualitative and quantitative in character. "Coughs" (gill purges), "yawns" (perhaps another purging behavior) and other activities, such as "turn arounds" in the test chamber, are interspersed among

the respiratory patterns of individual fish. A large number of "turn arounds" are often seen during the acclimazation period of a test. However, acclimazation is usually complete by 48 hours and a persistence of "turn arounds" is indicative of avoidance behavior (although such behavior is not possible in the test chamber). "Coughs" may or may not accompany such behavior; but, in any event, remain the most quantitative measure in the study (Drummond and Carlson, 1977).

A chronological summary of the respective rates of "coughs" observed in the tests is given in Table 9. In general, higher "cough" rates were elicited in both white perch and mummichog by chlorine than by ozone at similar test concentrations. The limited data preclude rigorous statistical analysis. However, the relationship between "cough" rates and the respective test concentrations of ozone (total oxidant) and total chlorine were examined for both white perch and for mummichog. A significant (P.05) positive correlation ($r = 0.527$ with 19df) existed between the "cough" rate of mummichog and concentration of total chlorine. The relationship, however, is not linear (Fig. 66). Correlations between "cough" rate and biocide concentration were not significant (P.05) for ozone with mummichog nor for either ozone or chlorine with white perch. The relationship between "cough" rate and respective biocide concentration is shown in Figure 67 for mummichog exposed to ozonated thermal effluent; Figure 68 for white perch exposed to chlorinated thermal effluent and in Figure 69 for white perch exposed to the ozonated thermal discharge. Although the relationships are statistically insignificant (P.05) "cough" rates of white perch appear to increase with increases in total

chlorine concentration but to decrease with increasing concentrations of ozone.

Trends of "cough" rates of mummichog exposed to the ozonated thermal discharge changed with season (Table 9). During February and March "cough" rate increased with ozone (total oxidant) concentration, but generally decreased with increased concentrations in June. As in the avoidance tests, mummichog exposed to the higher concentrations of ozone were observed feeding on entrained zooplankton in the test chambers. In April no concentration of ozone tested elicited an observed "cough" response.

Summary and Conclusions

Although limited, the results of tests evaluating the comparative effects of chlorinated and ozonated thermal discharges on mummichog and white perch indicate that the biological effects of ozonation are much less severe than those of chlorination. Not surprisingly the data also show white perch to be more sensitive than mummichog to the tested biocides. The 96 hour ILC_{50} (for a 2 hour intermittent exposure) for mummichog exposed to chlorine was about 0.54 mg/l but only 0.10 mg/l for white perch. Contrastingly, levels of 1 mg/l ozone (as total oxidant) failed to cause any mortality with mummichog or white perch.

The relative effects of ozonation and chlorination in the behavioral studies were similar to those observed in the toxicity studies. "Cough" rates were higher in chlorinated than in ozonated thermal discharges at similar test concentrations. The avoidance concentrations of mummichog averaged 0.09 mg/l total chlorine but exceeded ozone (total oxidant) concentrations of 0.42 mg/l.

White perch avoided an average 0.10 mg/l ozone (as total oxidant) but, at best, avoided an average 0.04 mg/l total chlorine. As expected, avoidance concentrations of white perch were less than those for mummichog and all determined avoidance concentrations were less than lethal levels.

The results of these studies can be compared with those conducted at other laboratories. The biological effects of any oxidizing biocide on a given species, however, are usually site specific. Some difference is due to laboratory and test population differences but much can be attributed to differences in quality of dilution water. Compared to the $ILC_{50}(96,2)$ of 0.10 mg/l total chlorine found at Bergen the 96 hour LC_{50} for white perch continuously exposed to chlorine proportionally diluted with water from the Delaware River estuary averaged 0.22 mg/l total chlorine with a standard deviation of 0.08 (PSE&G, 1978). (Contrastingly, Wedemeyer, et al (1979) reported a 96 hour LC_{50} averaging 0.009 mg/l ozone (as total oxidant) for rainbow trout, Salmo gairdneri, under conditions of continuous exposure. However, salmonids have been shown to be more sensitive than other fishes to oxidizing biocides.) The chlorine avoidance concentrations of white perch tested at Bergen averaged 0.04 mg/l total chlorine but averaged 0.06 mg/l total chlorine when tested in Delaware estuarine waters (Meldrim and Fäva, 1977). Such differences in white perch test results may be due to the limited data at Bergen, but are more likely attributable to the poor water quality at that site.

Although the amount of data obtained at Bergen is not large

it is indicative of the comparative biological effects in despoiled waters. As such it is valuable and points to some beneficial effects to be obtained from ozonation. Assuming such waters will be improved, however, concern then arises over the comparative effects of chlorination and ozonation in waters which support large populations of aquatic organisms. Such an evaluation will be the objective at the Mercer Generating Station.

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Table 1. - Results of acute toxicity tests with mummichog, Fundulus heteroclitus, exposed to various concentrations of chlorine for two hours per day for five consecutive days.

DATE	MEAN LENGTH (TL MM)	SALINITY (PPT)	TEST TEMP. (C)	DISS. O2 (MG/L)	PH	TOTAL CHLOR. (MG/L)	TIME(HRS.) FROM START OF TEST	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
FUNDULUS HETEROCLITUS													
12 FEB 79	39.7	1	16	3.8	7.4	0.00	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	43.8	1	16	3.8	7.4	0.00	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	0.00	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	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

Table 2. - Results of acute toxicity tests with mummichog, Fundulus heteroclitus, exposed to various concentrations of ozone for two hours per day for five consecutive days.

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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
FUNDULUS HETEROCLITUS													
12 FEB 79	47.7	1	16	3.8	7.4	0.04	0	10	7	-	10	-	-
							4	10	0	0	10	0	0
							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	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
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	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	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

Table 3. - Results of toxicity tests with chlorine on mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana; and grass shrimp, Palaemonetes pugio, conducted during March 1979.

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	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
FUNDULUS HETEROCLITUS													
20 MAR 79	68.2	0.5	19	5	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
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	62.5	0.5	19	5	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	69.6	0.5	19	5	7.4	0.04	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	68.9	0.5	19	5	7.4	0.4	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
20 MAR 79	67.8	0.5	19	5	7.4	0.09	0	10	-	-	10	-	-
							96	10	0	0	10	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	NO. ALIVE	*CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
MENIDIA BERYLLINA													
20 MAR 79	50.2	0.5	19	5.6	7.4	0.95	0	5	-	-	5	-	-
							0.6	5	0	0	0	5	0
20 MAR 79	45	0.5	19	5.6	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	5.6	7.4	0.46	0	5	-	-	5	-	-
							0.6	5	0	0	4	1	3
							0.9	5	0	0	0	5	0
MORONE AMERICANA													
27 MAR 79	156	1	14.5	6.9	7.5	0.97	0	5	-	-	5	-	-
							1.5	5	0	0	0	5	0
27 MAR 79	153.6	1	14.5	6.9	7.5	0.02	0	5	-	-	5	-	-
							96	5	0	0	5	0	0
27 MAR 79	159	1	14.5	6.9	7.5	0.63	0	5	-	-	5	-	-
							1.5	5	0	0	0	5	0
27 MAR 79	154.4	1	14.5	6.9	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	5	0
27 MAR 79	156.2	1	14.5	6.9	7.5	0.37	0	5	-	-	5	-	-
							1.5	5	0	0	1	4	1
							24	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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
PALAEMONETES PUGIO													
27 MAR 79	25.6	1	14.5	6.9	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	6.9	7.5	0.63	0	10	-	-	10	-	-
							19	10	0	0	9	1	0
							47	10	0	0	8	2	0
							69	10	0	0	7	3	0
							96	10	0	0	6	4	0
27 MAR 79	27	1	14.5	6.9	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	25.7	1	14.5	6.9	7.5	0.87	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
27 MAR 79	25.7	1	14.5	6.9	7.5	0.02	0	10	-	-	10	-	-
							43	10	0	0	9	1	0
							96	10	0	0	9	1	0

Table 4. Results of toxicity tests with ozone (as total oxidant) on silvery minnow, Hybog thus nuchalis; spottail shiner, Notropis hudsonius; mummichog, Fundulus heteroclitus; tidewater silverside, Menidia beryllina; white perch, Morone americana, and grass shrimp, Palaemonetes pugio, conducted during March 1979. * = levels 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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
HYBOGNATHUS NUCHALIS													
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	4
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	88.2	1	15.5	*	7.5	0.71	0	8	-	-	5	-	-
							48	8	0	0	5	0	0
30 MAR 79	88.7	1	15.5	*	7.5	0.39	0	8	-	-	9	-	-
							48	8	0	0	9	0	0
NOTROPIS HUDSONIUS													
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
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

Table 4. - 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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
FUNICULUS HETEROCLITUS													
20 MAR 79	57.1	0.5	19	*	7.4	1	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0
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	58.1	0.5	19	*	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	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	*	7.4	0.13	0	10	-	-	10	-	-
							19.5	9	1	0	10	0	0
							96	9	1	0	10	0	0

Table 4. - 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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	NO. ALIVE	EXPERIMENTAL NO. DEAD	NO. WITH L.O.E.
MENIDIA BERYLLINA													
20 MAR 79	46.8	0.5	19	*	7.4	0.09	0 72	5 5	- 0	- 0	5 5	- 0	- 0
20 MAR 79	41.8	0.5	19	*	7.4	1	0 19.5 72	5 5 5	- 0 0	- 0 0	5 4 4	- 1 1	- 0 0
20 MAR 79	47	0.5	19	*	7.4	0.18	0 44 72	5 5 5	- 0 0	- 0 0	5 4 4	- 1 1	- 0 0
20 MAR 79	47.6	0.5	19	*	7.4	0.49	0 72	5 5	- 0	- 0	5 5	- 0	- 0
MORONE AMERICANA													
23 MAR 79	192.8	1	15.5	*	7.5	0.97	0 96	5 5	- 0	- 0	5 5	- 0	- 0

Table 4. - 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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
PALAEMONETES PUGIO													
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
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	25	0.5	19	*	7.4	0.18	0	10	-	-	10	-	-
							44	9	1	0	8	2	0
							72	9	1	0	8	2	0
20 MAR 79	24.1	0.5	19	*	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
20 MAR 79	27	0.5	19	*	7.4	0.49	0	10	-	-	10	-	-
							44	9	1	0	10	0	0
							72	9	1	0	10	0	0
28 MAR 79	27.1	1	15.5	*	7.5	0.39	0	10	-	-	10	-	-
							96	10	0	0	10	0	0
28 MAR 79	28.3	1	15.5	*	7.5	0.15	0	10	-	-	9	-	-
							65	10	0	0	7	2	0
							96	10	0	0	7	2	0
28 MAR 79	26.2	1	15.5	*	7.5	0.71	0	10	-	-	11	-	-
							96	10	0	0	11	0	0

Table 4. - 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	NO. ALIVE	CONTROL NO. DEAD	NO. WITH L.O.E.	EXPERIMENTAL NO. ALIVE	NO. DEAD	NO. WITH L.O.E.
PALAEMONETES PUGIO													
22 MAR 79	21.6	1	15.5	*	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 5. - Summary of chlorine avoidance tests with the mummichog, Fundulus heteroclitus.

** = 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)		CHLOR. AVOID.
								CONT.	EXP.	CONT.	EXP.	CONC. (MG/L) 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	

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Table 6. - Summary of chlorine avoidance tests with the white perch, Morone americana.

DATE	REPLICATE	NO. OF FISH PER REPLICATE	MEAN LENGTH (MM)	LIGHT LEVEL (LUX)	PH	SALINITY (PPT)	TEST TEMP. (C)		DISSOLVED OXYGEN (MG/L)		CHLOR. AVOID.	
							CONT.	EXP.	CONT.	EXP.	CONC. (MG/L) TOTAL	
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	

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Table 7. - Summary of ozone avoidance tests with the mummichog, *Fundulus heteroclitus*.

* = levels of dissolved oxygen exceed 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)		DISSOLVED OXYGEN (MG/L)		OZONE AVOID. CONC. TOTAL OXIDANT (MG/L)	
							CONT.	EXP.	CONT.	EXP.		
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	64.0	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	7.9	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	**

Table 8. - Summary of ozone avoidance tests with the 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)		OZONE AVOID. CONC. TOTAL OXIDANT (MG/L)
								CONT.	EXP.	CONT.	EXP.	
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	

Table 9. - A chronological summary of test conditions and "cough" rates observed and noted on physiographic traces of mummichog, *Fundulus heteroclitus*, and white perch, *Morone americana*, exposed to chlorinated (1) or ozonated (2) thermal discharges.

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 9. - Continued.

DATE	BIOCIDES	PH	SALINITY (PPT)	CONC. (MG/L)	TEMP. (C)	D.O. (MG/L)	COUGH RATE (N/MIN)
FUNDULUS HETEROCALITUS							
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

BIOLOGICAL EVALUATION LABORATORY

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

Figure 1. - Diagram of the Biological Evaluation Laboratory and equipment.

Figure 2. - The 96 hour percent mortality of the mummichog, Fundulus heteroclitus, for two hour daily exposures to the respective concentrations (mg/l) of total chlorine. The number of data points at a given percent mortality is indicated numerically. The 2 hour intermittent LC_{50} at 96 hours is about 0.54 mg/l total chlorine.

Figure 3. - The 96 hour percent mortality of the white perch, *Morone americana*, for two hour daily exposures to the respective concentrations (mg/l) of total chlorine. The number of data points at a given percent mortality is indicated numerically. The 2 hour intermittent LC₅₀ at 96 hours is about 0.1 mg/l total chlorine.

Figure 4. - Total chlorine avoidance concentrations (mg/l) of mummichog, Fundulus heteroclitus, plotted against their respective test temperatures (C).

Figure 5. - Total chlorine avoidance concentrations (mg/l) of white perch, Morone americana, plotted against their respective test temperatures (C).

Figure 6. - Ozone avoidance concentrations (as mg/l total oxidant) of white perch, Morone americana, plotted against their respective test temperatures (C).

Figure 7. - Physiographic traces of "cough" responses of mummichog (top) and white perch (bottom) immediately prior to exposure to ozone. "X's" mark traces for which "coughs" were observed. Time of testing was 66 hours after being placed in test apparatus. Tests were conducted at pH = 6.7 and salinity = 1 ppt.

Figure 8. - Physiographic traces of "cough" responses of mummichog (top) and white perch (bottom) exposed to 0.03 mg/l ozone. "X's" mark traces for which "coughs" were observed. Time of testing was 66 hours 30 minutes after being placed in test apparatus. Tests were conducted at pH = 6.7 and salinity = 1 ppt.

Figure 9. - Physiographic traces of "cough" responses of mummichog on 23 March 1979 immediately prior to exposure to chlorine (top) and oxone (bottom). Ambient water chamber traces are in middle. Base line is from time and event marker (dashes are 1 minute apart). Tests were conducted at pH = 6.9 and salinity = 0.5 ppt.

Chlorine = 0.05 mg/l; Temp = 21 C; DO = 2.7 mg/l; Cough rate = 0.38/min

Untreated: Temp = 21 C; DO = 2.7 mg/l

Ozone = 0.4 mg/l; Temp = 21 C; Cough rate = 1/min

Time and event

48566

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Figure 10. - Physiographic traces of "cough" responses of mummichog on 23 March 1979 exposed to 0.05 mg/l total chlorine and 0.40 mg/l ozone (as total oxidant). "C's" mark traces for which "coughs" were observed; "Y's" indicate "yawns". Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 6.9 and salinity = 0.5 ppt.

Figure 11. - Physiographic traces of "cough" responses of mummichog on 23 March 1979 exposed to 0.15 mg/l total chlorine and 1.0 mg/l ozone (as total oxidant). "C's" mark traces for which "coughs" were observed; "Y's" indicate "yawns" and "TA" indicates fish turning around in test chamber. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 6.9 and salinity = 0.5 ppt.

Figure 12. - Physiographic traces of "cough" responses of mummichog on 23 March 1979 exposed to 0.15 mg/l total chlorine and 0.70 mg/l ozone (as total oxidant). "C's" mark traces for which "coughs" were observed. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 6.9 and salinity = 0.5 ppt.

Untreated; Temp = 23 C; DO = 5.0 mg/l; Cough rate = 0/min

Untreated; Temp = 23 C; DO = 5.0 mg/l

Untreated; Temp. = 23 C; DO = 5.0 mg/l

Untreated; Temp = 23 C; DO = 5.0 mg/l; Cough rate = 0/min

Time	Event
12:00	Start of the day
12:30	Lunch break
1:00	First class
1:30	Second class
2:00	Third class
2:30	Fourth class
3:00	Fifth class
3:30	Sixth class
4:00	Seventh class
4:30	Eighth class
5:00	Ninth class
5:30	Tenth class
6:00	End of the day

30732

4

SECRET

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Figure 13. - Physiographic traces of "cough" responses of mummichog on 19 April 1979 exposed to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.1 and salinity = 1 ppt.

Chlorine = 0.10 mg/l; Temp = 23 C; DO = 5.0 mg/l; Cough rate = 0.4/m

Untreated; Temp = 23 C; DO = 5.0 mg/l

Untreated; Temp = 23 C; DO = 5.0 mg/l

Untreated; Temp = 23 C; DO = 5.0 mg/l

Time and Event

46

64766

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 14. - Physiographic traces of "cough" responses of mummichog on 19 April 1979 exposed to 0.10 mg/l total chlorine and untreated condenser effluent. "C's" mark traces for which "coughs" were observed. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.1 and salinity = 1 ppt.

Untreated; Temp = 23 C; DO = 5.0 mg/l

Ozone = 0.17 mg/l; Temp = 23 C; DO = 15.2 mg/l; Cough rate = 0/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 15. - Physiographic traces of "cough" responses of mummichog on 19 April 1979 exposed to 0.17 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.1 and salinity = 1 ppt.

Untreated; Temp = 21 C; DO = 4.3 mg/l; Cough rate = 0/min

Untreated; Temp = 21 C; DO = 5.9 mg/l

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 16. - Physiographic traces of "cough" responses of mummichog on 20 April 1979 exposed to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1 ppt.

Chlorine = 0.05 mg/l; Temp = 21 C; DO = 4.3 mg/l; Cough rate = 0/min

Untreated; Temp = 21 C; DO = 5.9 mg/l

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 17. - Physiographic traces of "cough" responses of mummichog on 20 April 1979 exposed to 0.05 mg/l total chlorine and to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1 ppt.

Chlorine = 0.12 mg/l; Temp = 21 C; DO = 4.3 mg/l; Cough rate = 0/min

Untreated; Temp = 21 C; DO = 5.9 mg/l

Time and Event

39851

50

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Figure 18. - Physiographic traces of "cough" responses of mummichog on 20 April 1979 exposed to 0.12 mg/l total chlorine and to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1 ppt.

Untreated; Temp = 21 C; DO = 5.6 mg/l

Ozone = 0.17 mg/l; Temp = 22 C; DO = 11.2 mg/l; Cough rate = 0/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 19. - Physiographic traces of "cough" responses of mummichog on 20 April 1979 exposed to 0.17 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1 ppt.

Figure 20. - Physiographic traces of "cough" responses of mummichog on 20 April 1979 exposed to 0.23 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on time and event line are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1 ppt.

Chlorine = 0.0 mg/l (untreated); Temp = 24 C; DO = 4.5 mg/l; 1.8 coughs/min (observed)

Untreated; Temp = 24 C; DO = 4.0 mg/l

Time and Event

93529

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 21. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in untreated chlorine chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Chlorine = 0.01 mg/l; Temp = 24C; DO = 4.5 mg/l; 1.4 coughs/min (observed)

Untreated; Temp = 24C; DO = 4.0 mg/l

Time and Event

463538

Figure 22. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.01 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Chlorine = 0.02 mg/l; Temp = 24 C; DO = 4.5 mg/l; 7.2 coughs/min (observed)

Untreated: Temp = 24 C; DO = 4.0 mg/l

Time and Event

◊ NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 23. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.02 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Chlorine = 0.03 mg/l; Temp = 24 C; DO = 4.5 mg/l; 5.2 coughs/min (observed)

Untreated; Temp = 24 C; DO = 4.0 mg/l

Time and Event

463557

Figure 24. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.03 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Chlorine = 0.04 mg/l; Temp = 24 C; DO = 4.5 mg/l; 4.2 coughs/min (observed)

Untreated; Temp = 24 C; DO = 4.0 mg/l

Time and Event

463575

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 25. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.04 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Figure 26. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.05 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2 ppt.

Figure 27. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in untreated ozone chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 2 ppt.

Figure 28. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.04 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 2 ppt.

Figure 29. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.06 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 2 ppt.

Figure 30. - Physiographic traces of "cough" responses of white perch on 17 May 1979 exposed to 0.11 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 2 ppt.

Chlorine = 0.0 mg/l; Temp = 26 C; DO = 3.0 mg/l; Cough rate = 1/min

Untreated; Temp = 27 C; DO = 3.8 mg/l

Time and Event

463851

69

SQUARED 3 MM X 5 MM

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 31. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

chlorine = 0.01 mg/l; Temp = 27.5 C; DO = 3.6 mg/l; Cough rate = 1/min

Untreated; Temp = 26 C; DO = 3.8 mg/l

Time and Event

463860

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 32. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.01 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Chlorine = 0.08 mg/l; Temp = 27.5 C; DO = 3.6 mg/l, Cough rate = 1.25/min

Untreated; Temp = 26 C; DO = 3.8 mg/l

Time and Event

SQUARES 5 MM X 5 MM.

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 33. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.08 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Chlorine = 0.10 mg/l; Temp = 29.5; DO = 3.6 mg/l; Cough rate = 1.5/min

Heavy Respiration

Untreated; Temp = 26 C; DO = 3.8 mg/l

Time and Event

462910

Figure 34. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.10 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

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Chlorine = 0.11 mg/l; Temp = 28 C; DO = 3.6 mg/l; Cough rate = 1.4/min

Heavy Respiration

Untreated; Temp = 26 C; DO = 3.8 mg/l

Time and Event

SQUARES 1 MM 1.5 MM

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

463897

Figure 35. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.11 mg/l total chlorine and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in chlorinated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Chlorine = 0.13 mg/l; Temp = 30 C; DO = 3.6 mg/l; Cough rate = 1.85/min

Time and Event

SQUARES 5 MM X 5 MM

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 36. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.13 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

463926

Chlorine = 0.14 mg/l; Temp = 30 C; DO = 3.6 mg/l; Cough rate = 2/min

Time and Event

463920

Figure 37. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.14 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Chlorine = 0.15 mg/l; Temp = 30 C; DO = 3.6 mg/l; Cough rate = 9.4/min

Figure 38. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.15 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

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Chlorine = 0.17 mg/l; Temp = 30.5 C; DO = 3.6 mg/l; Cough rate = 2.6/min

Time and Event

405974

RECORDED FROM 12-10-79
7 SQUARES PER MIN

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.
NARCO BIO-SYSTEMS, INC., (INCUBATOR, TANKS, ETC.)

Figure 39. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.17 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

chlorine = 0.18 mg/l; Temp = 30 C; DO = 3.6 mg/l; Cough rate = 4.8/min

Figure 40. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.18 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted as pH = 7.2 and salinity = 1.5 ppt.

PHYSIOGRAPHY 4-CHANNEL
chlorine = 0.19 mg/l; Temp = 30 C; DO = 3.6 mg/l; Cough rate = 3.6/min

Time and Event

463944

SOLARIS 1000

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 41. - Physiographic traces of "cough" responses of mummichog on 21 June 1979 exposed to 0.19 mg/l total chlorine. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Untreated; Temp = 26 C; DO = 4.1 mg/l; Cough rate = 0.21/min

Turn
around

Turn around

Ozone = 0.0 mg/l; Temp = 25.5 C; DO = 3.0 mg/l; Cough rate = 0.8/min

Time and Event

164050

74

SCALE 5 MM PER MIN.

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 42. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

treated; Temp = 25.5; DO = 5.1 mg/l

Ozone = 0.01 mg/l; Temp = 27 C; Cough rate = 0.83/min

Time and Event

164073

51

Figure 43. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.01 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

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untreated; Temp = 25.5 C; DO = 5.1 mg/l

Ozone = 0.06 mg/l; Temp = 28 C; Cough rate = 0.4/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 44. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.06 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

untreated; Temp = 26 C; DO = 5.1 mg/l

Ozone = 0.11 mg/l; Temp = 28 C; Cough rate = 0.6/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 45. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.11 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

untreated; Temp = 26.5 C; DO = 5.1 mg/l

Ozone = 0.14 mg/l; Temp = 29 C; Cough rate = 1/min

Time and Event

464115

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 46. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.14 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

untreated; Temp = 26.5 C; DO = 5.1 mg/l

Ozone = 0.22 mg/l; Temp = 30 C; Cough rate = 0.4/min

Time and Event

SQUARES 5 MM x 5 MM

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 47. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.22 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

ntreated ; Temp = 26.5 C; DO = 5.1 mg/l

Ozone = 0.40 mg/l; Temp = 31.5 C; Cough rate = 0.2/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 48. - Physiographic traces of "cough" responses of mummichog on 22 June 1979 exposed to 0.40 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.3 and salinity = 1.5 ppt.

Figure 49. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Figure 50. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.01 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Figure 51. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.06 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Figure 52. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.14 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Figure 53. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.15 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

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Figure 54. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.22 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Figure 55. - Physiographic traces of "cough" responses of white perch on 22 June 1979 exposed to 0.38 mg/l ozone (as total oxidant). Dashes on top side of time and event line mark observed "coughs"; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 1.5 ppt.

Ozone = 0.0 mg/l; Temp = 25.5 C; DO = 4.8 mg/l; Cough rate = 3/min

Ozone = 0.0 mg/l; Temp = 25.5 C; DO = 4.8 mg/l

Untreated; Temp = 25.5 C; DO = 4.8 mg/l

Time and Event

464207

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Figure 56. - Physiographic traces of "cough" responses of mummichog on 26 June 1979 exposed to untreated condenser effluent. Dashes on top side of time and event line (with "X's") mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Figure 57. - Physiographic traces of "cough" responses of mummichog on 26 June 1979 exposed to 0.08 ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

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Figure 58. - Physiographic traces of "cough" responses of mummichog on 26 June 1979 exposed to 0.11 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity 2.5 ppt.

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Figure 59. - Physiographic traces of "cough" responses of mummichog on 26 June 1979 exposed to 0.18 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Figure 60. - Physiographic traces of "cough" responses of mummichog on 26 June 1979 exposed to 0.29 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

one = 0.25 mg/l; Temp = 31 C; DO > 20 mg/l; Cough rate = 0.4/min

Ozone = 0.25 mg/l; Temp = 31 C; DO > 20 mg/l

Untreated; Temp = 25.5 C; DO = 4.7 mg/l

Time and Event

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Figure 61. - Physiographic traces of "cough" responses of mummichog on 27 June 1979 exposed to 0.25 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Ozone = 0.25 mg/l; Temp = 31 C; DO > 20 mg/l

fish feeding off oxygen etc.

Ozone = 0.25 mg/l; Temp = 31 C; DO > 20 mg/l; Cough rate = 0.2/min

Untreated; Temp = 25.5 C; DO = 4.7 mg/l

Time and Event

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Figure 62. - Physiographic traces of "cough" responses of mummichog on 27 June 1979 exposed to 0.25 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in bottom ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Ozone = 0.30 mg/l; Temp = 31 C; DO > 20 mg/l

Ozone = 0.30 mg/l; Temp = 31 C; DO > 20 mg/l; Cough rate = 0/min

Untreated; Temp = 25.5 D; DO = 4.7 mg/l

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 63. - Physiographic traces of "cough" responses of mummichog on 27 June 1979 exposed to 0.30 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in bottom ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

zone = 0.30 mg/l; Temp = 31 C; DO > 20 mg/l; Cough rate = 0.6/min

Ozone = 0.30 mg/l; Temp 31 C; DO > 20 mg/l

Untreated; Temp = 25.5 C; DO = 4.6 mg/l

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 64. - Physiographic traces of "cough" responses of mummichog on 27 June 1979 exposed to 0.30 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in top ozonated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Physiographic Traces
Ozone = 0.30 mg/l; Temp = 31 C; DO > 20 mg/l

Ozone = 0.30 mg/l; Temp = 31 C; DO > 20 mg/l

Untreated; Temp = 25.5 C; DO = 4.7 mg/l; Cough rate = 1/min

Time and Event

NARCO BIO-SYSTEMS, INC., Houston, Texas, U.S.A.

Figure 65. - Physiographic traces of "cough" responses of mummichog on 27 June 1979 exposed to 0.30 mg/l ozone (as total oxidant) and to untreated condenser effluent. Dashes on top side of time and event line mark "coughs" observed in untreated chamber; those on bottom are 1 minute apart. Tests were conducted at pH = 7.2 and salinity = 2.5 ppt.

Figure 66. - The relationship between observed "cough" rate and test concentration for mummichog, Fundulus heteroclitus, exposed to the chlorinated thermal discharge. The number of data points at a given "cough" rate is indicated numerically.

Figure 67. - The relationship between observed "cough" rate and test concentration for mummichog, Fundulus heteroclitus, exposed to the ozonated thermal discharge. The number of data points at a given "cough" rate is indicated numerically.

Figure 68. - The relationship between observed "cough" rate and test concentration for white perch, Morone americana, exposed to the chlorinated thermal discharge. The number of data points at a given "cough" rate is indicated numerically.

Figure 69. - The relationship between observed "cough" rate and test concentration for white perch, Morone americana, exposed to the ozonated thermal discharge. The number of data points at a given "cough" rate is indicated numerically.

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070Meldrim, J.W.; Holmstrom, E.R.; Balog, G.E.

110Comparative evaluation of effects of ozonated and chlorinated thermal discharges on estuarine and freshwater organisms

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550TIC 560United States of America (USA) 570United States of America (USA)

700950 0462 710Ichthyological Associates, Inc., Ithaca, NY (USA)

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801FOSSIL-FUEL POWER PLANTS;CONDENSER COOLING SYSTEMS;ANTIPOULANTS:D;THERMAL EFFLUENTS;CHEMICAL EFFLUENTS:T1; OZONE:T2,Q1,D;CHLORINE:T3,Q1,D;AQUATIC ECOSYSTEMS;ESTUARIES;SURFACE WATERS;FRESH WATER;AQUATIC ORGANISMS;BIOLOGICAL EFFECTS:Q2,Q3;TOXICITY:Q2,Q3,D;FISHES:T4,D;MORTALITY:Q4,D;BEHAVIOR:Q4,D;COMPARATIVE EVALUATIONS;EXPERIMENTAL DATA:D; ISOLATED VALUES:D;GRAPHS:D;

T:Q1 CHEMICAL EFFLUENTS;OZONE

T:Q1 CHEMICAL EFFLUENTS;CHLORINE

T:Q2 OZONE;BIOLOGICAL EFFECTS

T:Q2 OZONE;TOXICITY

T:Q3 CHLORINE;BIOLOGICAL EFFECTS

T:Q3 CHLORINE;TOXICITY

T:Q4 FISHES;MORTALITY

T:Q4 FISHES;BEHAVIOR

T FISHES

950Although limited, the results of tests evaluating the comparative effects of chlorinated and ozonated thermal discharges on mummichog and white perch indicate that the biological effects of ozonation are much less severe than those of chlorination. The data also show white perch to be more sensitive than mummichog to the tested biocides. The relative effects of ozonation and chlorination in the behavioral studies were similar to those observed in the toxicity studies. Cough rates were higher in chlorinated than in ozonated thermal discharges at similar test concentrations. Avoidance concentrations of white perch were less than those for mummichog and all determined avoidance concentrations were less than lethal levels. The biological effects of any oxidizing biocide on a given species, however, are usually site specific. The chlorine avoidance concentrations of white perch tested at Bergen averaged 0.04 mg/l total chlorine but averaged 0.06 mg/l total chlorine when tested in Delaware estuarine waters. Although the amount of data obtained at Bergen is not large, it is indicative of the comparative biological effects in despoiled waters. Assuming such waters will be improved, however, concern then arises over the comparative effects of chlorination and ozonation in waters which support large populations of aquatic organisms. (ERB)

C00 -- 4384 - 2

CATEGORIES

EDB ☒
ERA ☒
EPA ☐
WDA ☐ALD ☐
INS ☐
RIP ☐
GAP ☐☐
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AUGMENTATION:

None

SPLIT	DESCRIPTORS	FLAGS
	Fossil-Fuel Power Plants	
	Condenser Cooling Systems	
	Antifoulants	D
	Thermal Effluents	
	Chemical Effluents	T1
	Ozone	T2, Q1, D
	Chlorine	T3, Q1, D
	Aquatic Ecosystems	
	Estuaries	
	Surface Waters	
	Freshwater	
	Aquatic Organisms	
	Biological Effects	Q2, Q3
	Toxicity	Q2, Q3, D
	Fishes	T4, D
	Mortality	Q4, D
	Behavior	Q4, D
	Comparative Evaluations	
	Experimental Data	D
	Isolated Values	D
	Isophs	D

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chlorine concentration but to decrease with increasing concentrations of ozone.

Trends of "cough" rates of mummichog exposed to the ozonated thermal discharge changed with season (Table 9). During February and March "cough" rate increased with ozone (total oxidant) concentration, but generally decreased with increased concentrations in June. As in the avoidance tests, mummichog exposed to the higher concentrations of ozone were observed feeding on entrained zooplankton in the test chambers. In April no concentration of ozone tested elicited an observed "cough" response.

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Summary and Conclusions

Although limited, the results of tests evaluating the comparative effects of chlorinated and ozonated thermal discharges on mummichog and white perch indicate that the biological effects of ozonation are much less severe than those of chlorination.

~~Not surprisingly~~ the data also show white perch to be more sensitive than mummichog to the tested biocides. The 96-hour ILC_{50} (for

a 2-hour intermittent exposure) for mummichog exposed to chlorines was about 0.54 mg/l but only 0.10 mg/l for white perch. Contrastingly, levels of 1 mg/l ozone (as total oxidant) failed to cause any mortality with mummichog or white perch.

→ The relative effects of ozonation and chlorination in the behavioral studies were similar to those observed in the toxicity studies. "Cough" rates were higher in chlorinated than in ozonated thermal discharges at similar test concentrations. The avoidance concentrations of mummichog averaged 0.09 mg/l total chlorine but exceeded ozone (total oxidant) concentrations of 0.42 mg/l.

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~~White perch avoided an average 0.10 mg/l ozone (as total oxidant) but, at best, avoided an average 0.04 mg/l total chlorine. As~~

~~Expected,~~ avoidance concentrations of white perch were less than those for mummichog and all determined avoidance concentrations were less than lethal levels.

~~The results of these studies can be compared with those conducted at other laboratories. The biological effects of any oxidizing biocide on a given species, however, are usually site specific. Some difference is due to laboratory and test population differences but much can be attributed to differences in quality of dilution water. Compared to the $ILC_{50}(96,2)$ of 0.10 mg/l total chlorine found at Bergen the 96 hour LC_{50} for white perch continuously exposed to chlorine proportionally diluted with water from the Delaware River estuary averaged 0.22 mg/l total chlorine with a standard deviation of 0.08 (PSE&G, 1978). (Contrastingly, Wedemeyer, et al (1979) reported a 96 hour LC_{50} averaging 0.009 mg/l ozone (as total oxidant) for rainbow trout, *Salmo gairdneri*, under conditions of continuous exposure. However, salmonids have been shown to be more sensitive than other fishes to oxidizing biocides.)~~

The chlorine avoidance concentrations of white perch tested at Bergen averaged 0.04 mg/l total chlorine but averaged 0.06 mg/l total chlorine when tested in Delaware estuarine waters. (Meldrim and Fava, 1977). Such

~~differences in white perch test results may be due to the limited data at Bergen, but are more likely attributable to the poor water quality at that site.~~

→ Although the amount of data obtained at Bergen is not large,

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→ it is indicative of the comparative biological effects in despoiled waters. ~~As such it is valuable and points to some beneficial effects to be obtained from ozonation.~~ → Assuming such waters will be improved, however, concern then arises over the comparative effects of chlorination and ozonation in waters which support large populations of aquatic organisms. ~~Such an evaluation will be the objective at the Mercer Generating Station.~~

(23)