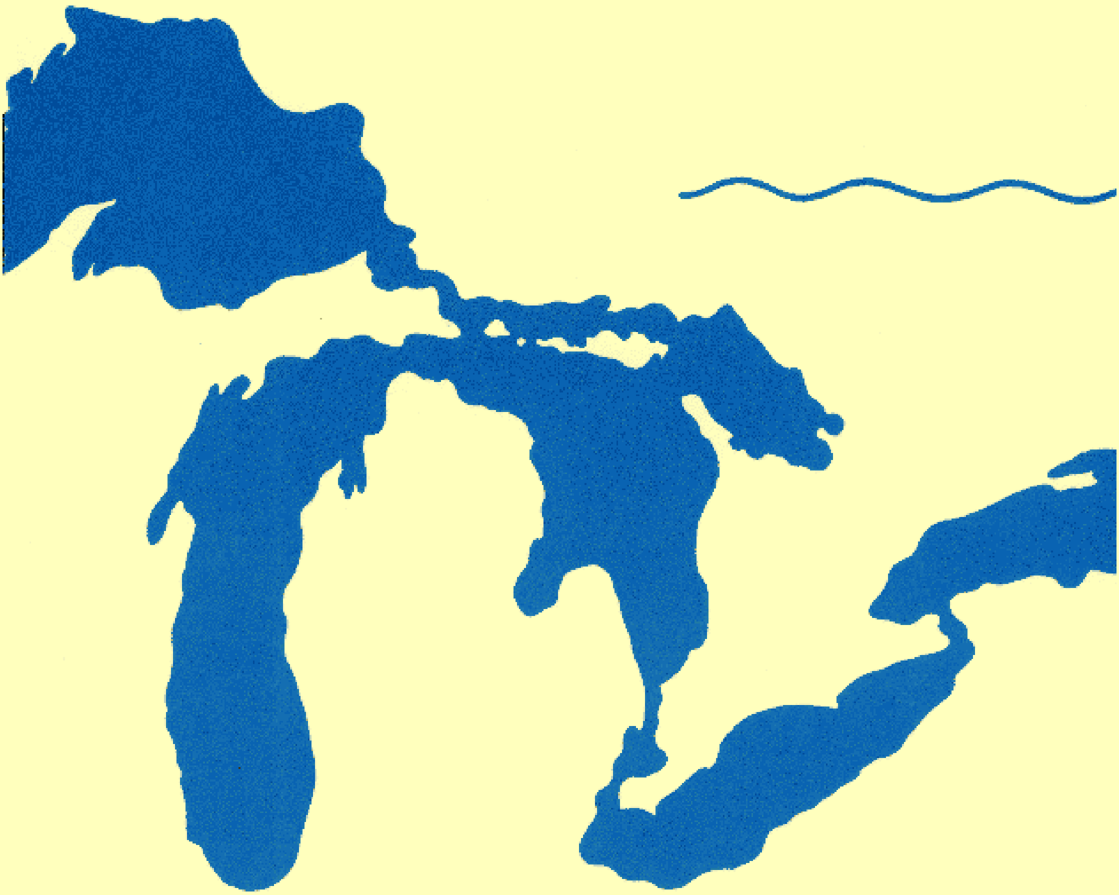
SENSITIVITY OF LAKE STURGEON (*ACIPENSER FULVESCENS*) TO THE LAMPRICIDE 3-TRIFLUOROMETHYL-4-NITROPHENOL (TFM) IN FIELD AND LABORATORY EXPOSURES



Great Lakes Fishery Commission

TECHNICAL REPORT 62

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TECHNICAL REPORT 62

Great Lakes Fishery Commission
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Ann Arbor, MI 48105-1563

February 1999

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ABSTRACT. The Sturgeon River-a tributary of Lake Superior in Houghton and Baraga Counties, MI - is a major producer of sea lampreys *(Petromyzon marinus)* and is a prime nursery area for juvenile lake sturgeons (Acipenser fulvescens). Prior to the application of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) in 1989, we ran on-site toxicity tests to determine the sensitivity of the lake sturgeon to TFM. Concentrations of TFM approximately 1.3 times the LC99.9 of sea lamprey larvae were not lethal to juvenile lake sturgeons. This difference in sensitivity to TFM between sea lamprey larvae and juvenile lake sturgeons would allow stream treatment without significant mortality of lake sturgeons. Follow-up, laboratory flow-through toxicity tests showed that juvenile lake sturgeons were more sensitive than northern pike *(Esox lucius),* muskellunge *(Esox masquinongy),* and rainbow trout *(Oncorhynchus mykiss).* Toxicity tests showed that pH significantly affected the toxicity of TFM to lake sturgeons, but changes in total alkalinity had little effect. Lampricide was applied to the Sturgeon River to kill larval sea lampreys in 1989 and 1994 at concentrations of TFM determined by on-site toxicity tests. Extensive post-treatment surveys found many dead sea lamprey larvae but almost no dead of nontarget species and no dead lake sturgeons.

INTRODUCTION

The Sturgeon River, a tributary of Lake Superior in Houghton and Baraga Counties, MI, is a major producer of sea lampreys (Petromyzon marinus) and has been treated with the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) 12 times since 1960. This river is a nursery area for juvenile lake sturgeons (Acipenser fulvescens). In 1989, the lake sturgeon was listed by the state of Michigan as a threatened species under the Michigan Endangered Species Act (Anonymous 1974) and by the federal government as a Category 2 species. The lake sturgeon was removed from the federal listing in July 1995.

The lampricide TFM is registered in the U.S. and Canada as a selective sea lamprey larvicide. However, some fish species, including black bullhead *(Ameiurus melas),* channel cattish *(Ictalurus punctatus),* northern pike *(Esox lucius),* and logperch *(Percina caprodes),* are sensitive to TFM (Applegate and King 1962; Marking and Olson 1975; Bills and Marking 1976). The concentrations of TFM that cause mortality of nontarget fish vary with pH. Concentrations that kill sea lampreys vary with pH and, to a lesser extent, with total alkalinity (Bills and Johnson 1992). TFM is significantly less toxic in water with high pH (Marking and Olsen 1975). The toxicity of TFM varies because the ratio of un-ionized to ionized TFM in water changes with pH. The un-ionized neutral form of an organic electrolyte crosses lipid membranes more readily and has a higher equilibrium coefficient for passage into biota than the charged form does, which, in turn, increases or decreases the amount available to produce toxicosis (Hunn and Allen 1974). Gilderhus et al. (1992) showed that increasing water pH by as little as 1 unit will render most treatments with TFM nontoxic. The relation between pH and toxicity of TFM to several salmonid species has been reported by Bills et al. (1988) Bills and Johnson (1992), and Klar (1993). However, no information is available on the effects of pH on the toxicity of TFM to the lake sturgeon.

On-site, flow-through toxicity tests provide information on the toxicity of TFM at pH and alkalinity conditions specific to a test stream. The tests also provide information needed to select a treatment concentration that is lethal to larval sea lampreys but produces minimal or no mortality among nontarget organisms. Laboratory flow-through toxicity tests compare the sensitivity of several nontarget species to TFM at selected combinations of water pH and alkalinity encountered during lampricide treatments. The objectives of this study were to:

- Determine the toxicity of TFM to sea lampreys and lake sturgeons on-site with Sturgeon River water in continuous-flow toxicity tests

- Determine a concentration of TFM that, when applied to the Sturgeon River, would be lethal to sea lampreys but not cause significant mortality of lake sturgeons

- Determine the sensitivity of lake sturgeons to TFM over the ranges of pHs and alkalinities that may be encountered during a lampricide application

- Compare the sensitivity of lake sturgeons, rainbow trout *(Oncorhynchus mykiss),* northern pike, and muskellunge *(Esox masquinongy)* to TFM

METHODS

On-Site Toxicity Tests

On-site continuous-flow toxicity tests were run at the Sturgeon River in a mobile bioassay trailer in 1989, 1993, and 1994 (Fig. 1). The tests were run in a toxicant delivery system similar to that described by Garton (1980) and modified by Bills and Johnson (1992). Stream water was pumped directly from the river to the bioassay trailer where TFM was introduced by automatic pipettor into the continuous-flow dilution system, which provided a proportional series of concentrations. Water volumes in the test containers were reduced from 40 L to approximately 10 L 5 min before toxicant delivery began. This reduction allowed a rapid rise in concentration in the tanks as they filled and provided a concentration profile for the test similar to that seen in streams during lampricide treatments. Concentrations reached desired levels in approximately 2 h and remained stable ($\pm$0.1 mg/L TFM) throughout the exposure. Concentrations of TFM were calculated for each container by averaging hourly results. The test done during the fall of 1989 included a stream-water control and five stream-water/lampricide mixtures. Each test vessel (40 L) received 1.0 L/min of stream water. Concentrations of TFM ranged from 1.0 to 3.5 mg/L. Field-grade TFM, 36% active ingredient (AI), was obtained from the American Hoechst Company. Solutions of TFM were prepared by diluting pre-weighed samples of field-grade TFM with de-ionized water.

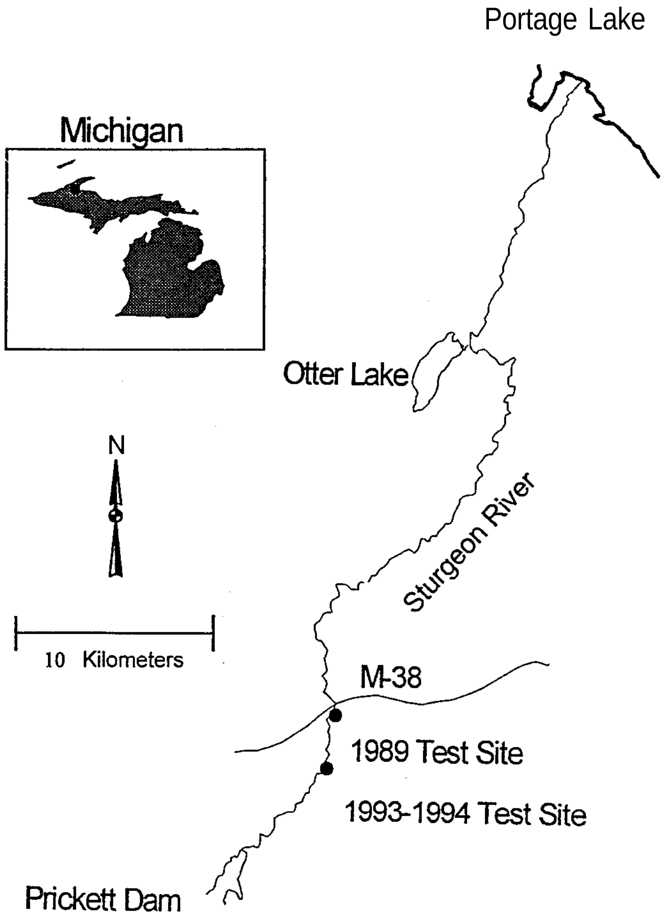

Figure 1. Map of the Sturgeon River, Baraga County, MI, including sites of 1989, 1993, and 1994 on-site toxicity tests.

In the fall of 1993 and 1994, the on-site toxicity tests were run with similar but expanded continuous-flow delivery systems to provide stream water or stream-water/toxicant mixtures at a rate of 0.75 L/min/ tank to eight tanks (1993) or ten tanks (1994). The exposure tanks (40 L) contained seven or nine concentrations of TFM and one control. Exposure concentrations of TFM varied:

- 1.2 to 4.6 mg/L in 1993
- 0.7 to 4.1 mg/L in 1994

Juvenile lake sturgeons (100 to 125 mm total length (TL)) were obtained from the St. Paul State Fish Hatchery, St. Paul, MN, for the test in 1989. They were transported by tank truck to the Sturgeon River test site and were held and acclimated to stream water in the transport tank for approximately 4 d before testing. In 1993 and 1994, lake sturgeons (133 to 218 mm TL, 13 g average weight) were cultured at the Upper Mississippi Science Center, Lacrosse, WI, and transported by tank truck to the test site where they were caged and held in the Sturgeon River for 1 wk. Dry food pellets were offered twice daily and were supplemented with frozen brine shrimp every third day during acclimation. Sea lamprey larvae (70 to 120 mm TL) were collected by electrofishing in the Sturgeon and Huron (Baraga County, MI) Rivers and were held in cages containing substrate for burrowing in the Sturgeon River.

In 1989, we exposed ten sea lamprey larvae and 15 juvenile lake sturgeons to each concentration of TFM for 12 h-the maximum exposure time expected in a stream treatment. Mortality of these fish was recorded hourly from 2 through 9 h; at 12 h; and at 2, 6, and 12-h post-exposure. Five juvenile lake sturgeons and five sea lamprey larvae were exposed to each concentration of TFM in the toxicity tests done in 1993. In 1994, the number was increased to ten of each species per concentration. Mortality of sea lamprey larvae and lake sturgeons was recorded hourly from 2 through 9 h, at 12 h, and at 12-h post-exposure. The criterion for death was lack of movement of the fish. Lethal concentrations producing 50% mortality (LC50) and their 95% confidence intervals were calculated according to the method of Litchfield and Wilcoxon (1949).

Water temperatures and pH in exposure tanks were monitored hourly with Beckman meters:

- Beckman pHI 21 meter in 1989
- Beckman pHI 10 meter in 1993 and 1994

Total alkalinity was determined potentiometrically (American Public Health Association et al. 1985). Concentrations of TFM in exposure water were determined hourly by reverse-phase high-performance liquid chromatography (HPLC) during the 1989 tests (Dawson 1982; Johnson 1982). Grab samples were collected from each test container and analyzed immediately. Sample absorbance at 3 13 nm was compared with blank and standard solutions prepared on-site with pre-formulated TFM-standardized stock solutions. Equipment used for analysis included a Waters Model 5 10 solvent delivery system, Model 440 absorbance detector, and Model U6K injector and a Hewlett-Packard Model 3390A integrator. Operating conditions were:

- Stationary phase-Waters 3.9 x 150-mm Bondapack C_{18} column
- Mobile phase-75% HPLC-grade methanol/25% 0.01 M acetate buffer
- Flow rate - 1.4 mL/min
- Sample injection volume - 25 μL

In the 1993 and 1994 tests, we determined concentrations of TFM with a Sequoia-Turner Model 340 spectrophotomer used according to established procedures (Bouchard and Schleen 1989; Klar 1993). Again, grab samples were collected hourly and analyzed immediately for TFM content. We compared sample absorbance at 395 nm with blank and standard solutions prepared on-site with pre-formulated TFM-standardized stock solutions.

Laboratory Toxicity Tests

We ran continuous-flow toxicity tests at the Upper Mississippi Science Center, Lacrosse, WI, with a dilution system designed by Garton (1980) and modified by Bills and Johnson (1992). Procedures for these tests followed those described by Klar (1993). Duration of the tests was 12 h of exposure followed by 12 h of post-exposure observation. The test waters had pH values of 7.2, 7.7, and 8.2, respectively, and total alkalinities of 30, 85, and 215 mg/L, respectively, as $CaCo_3$ at 12°C.

Field-grade TFM, 36% AI, was obtained from the American Hoechst. Test-chemical purity was confirmed by comparing the field-grade TFM with technical-grade TFM, 99% AI from American Tokyo Kasei by reverse-phase HPLC (Dawson 1982).

Test fish were obtained from the following facilities:

- Fingerling lake sturgeon--Wild Rose State Fish Hatchery, WI
- Rainbow trout-Erwin National Fish Hatchery, TN
- Northern pike-Genoa National Fish Hatchery, WI
- Muskellunge - Spooner State Fish Hatchery, WI

Fish were obtained as eggs or fry and cultured at the Upper Mississippi Science Center. Fish care and maintenance procedures followed those outlined by Hunn et al. (1968). Acclimation of test organisms to test conditions followed procedures outlined by the Committee on Methods for Toxicity Tests with Aquatic Organisms (1975). Ten fish were exposed to each concentration of TFM and to the control water.

Exposure water was prepared by de-ionizing and reconstituting well water according to standard procedures outlined by the American Society for Testing and Materials (1980). The pH value of the exposure water was maintained ($\pm$ 0.1 unit) throughout the test by addition of weak hydrochloric acid (0.1 N) or sodium hydroxide (0.1 N) to the headbox of the dilution system with an adjustable Micromedic® automatic pipettor from ICN Biomedical. The pH was measured hourly with a Beckman Theta II pH meter. Alkalinity was measured at 0 h and 6 h of exposure according to the American Public Health Association et al. (1985). Dissolved oxygen was measured at the beginning and end of each exposure with a Yellow Springs Model 58 dissolved oxygen meter. Mortality was recorded hourly for the duration of exposure and at 12-h post exposure. Concentrations of TFM that produced 25% and 50% mortality and significant differences between LC50s were calculated according to the method of Litchfield and Wilcoxon (1949).

Concentrations of TFM in water were determined hourly by reverse-phase HPLC according to the methods of Dawson (1982). Analysis equipment included a Waters Model 481 Lambda-Max LC spectrophotometer, Model 5 10 pump, Model 710B WISP autosampler, and Model 730 data module. Operating conditions were:

- Stationary phase-30 cm x 4 mm Varian Micropak MCH-10 column
- Mobile phase - 65% HPLC-grade methanol/35% 0.01 M acetate buffer
- Flow rate-2.0 mL/min
- Attenuation - 16 millivolts

Post-Treatment Assessment

TFM was applied for 12 h at Prickett Dam (Fig. 1) in September 1989 at 3.5 mg/L. This concentration was based on data from pretreatment toxicity tests. Sea lamprey-control personnel surveyed and collected extensively during and after the treatment to confirm treatment efficacy and mortality among nontarget fishes. Assessment teams collected using scap nets for 50 man-hours throughout the treatment area. In addition, seven fyke nets were fished at two sites for a total of 169 h to collect any dead or dying lake sturgeons and sea lamprey larvae.

TFM was applied again at Prickett Dam in October 1994. The concentration of TFM applied averaged 2.4 mg/L at the dam. Assessment teams collected during and after the treatment for 19.1 man-hours at 11 sites in the treatment area.

RESULTS

On-Site Toxicity Tests

The average temperature of the exposure water during the toxicity test in 1989 was 20.9°C, mean pH was 8.05, and total alkalinity was 79 mg/L as $CaCO_3$ (Table 1). Average temperatures of the exposure water varied little (13.3-14.9°C) among the 1993 and 1994 tests (Table 1). The mean pH of the exposure waters varied from 7.09 to 8.01 and from 7.73 to 7.77 in the 1993 and 1994 tests, respectively. Total alkalinity averaged 75 and 60 mg/L as $CaCO_3$ in 1993 and 1994, respectively.

No mortality of lake sturgeons was observed in 1989 at concentrations of TFM $\leq$ 3.5 mg/L in 12-h exposures. However, 100% mortality of sea lamprey larvae was observed in less than 12 h at concentrations of TFM $\geq$ 2.6 mg/L (Table 2). The difference between the observed no effect (mortality) concentration for lake sturgeon and the observed LC100 for sea lamprey larvae was greater than 1.3 to 1.

Lake sturgeons also were less sensitive than sea lamprey larvae to TFM in the 1993 tests. In the 12-h exposures at $\leq$ 2.4 mg/L TFM, no lake sturgeons were killed. However, mortality of sea lamprey larvae was 100% at $\geq$ 1.9 mg/L TFM and 80% at 1.8 mg/L TFM in 12-h exposures (Table 2). These findings are consistent with those in 1989 that showed that lake sturgeons tolerate concentrations of TFM between 1.2 and 1.3 times those needed to kill sea lamprey larvae. Lake sturgeons were not exposed to concentrations of TFM between 2.4 mg/L (which produced no mortality) and 2.8 mg/L (which produced 20% mortality). Hence, the ratio may be slightly higher. The LC50s for sea lamprey larvae and juvenile lake sturgeons were significantly different ($p < 0.05$). A comparison of LC50s from 1993 tests showed that sea lamprey larvae were about twice as sensitive as lake sturgeons to TFM (Table 1).

Table 1. Water chemistry parameters, test dates, and toxicity of TFM (12-h LC50s (mg/L) and 95% confidence intervals (CI) for sea lamprey larvae and juvenile lake sturgeons in flow-through tests conducted on the Sturgeon River, Baraga County, MI. Ranges for pH and temperature, sample sizes, and CIs are given in parentheses.

Test date	Species	Mean pH	Alkalinity (mg/L as $CaCo_3$)	Temperature (°C)	12-h LC50
August 30,1989	Sea lamprey	8.05 (7.93-8.16) (N=65)	79	20.9 (0.5-21.3) (N=11)	2.09 (1.73-2.52)
	Lake sturgeon	8.05 7.93-8.16) (N=71)	79	20.9 (20.5-21.3) (N=11)	> 3.5 ---
September 24, 1993	Sea lamprey	7.98 (.85-8.26) (N=57)	75	14.8 (11.9-16.2) (N=37)	1.69 (1.49-1.92)
	Lake sturgeon	8.00 (7.85-8.32) (N=85)	75	14.2 (11.9-16.2) (N=52)	3.10 (2.65-3.63)
September 26,1993	Sea lamprey	7.99 (7.84-8.26) (N=70)	75	14.5 (13.5-15.6) (N=45)	1.72 (1.53-1.93)
	Lake sturgeon	8.01 (7.84-8.26) (N=84)	75	14.9 (13.5-15.6) (N=51)	3.33 (2.87-3.86)
October 6, 1994	Sea lamprey	7.76 (7.65-7.90) (N=70)	60	14.2 (12.3-15.5) (N=13)	1.29 (1.20-1.39)
	Lake sturgeon	7.73 (7.64-7.87) (N=65)	60	14.2 (12.3-15.5) (N=13)	2.40 (2.14-2.69)
October 8,1994	Sea lamprey	7.77 (7.67-7.90) (N=85)	60	13.3 (12.9-13.5) (N=13)	1.33 (1.20-1.48)
	Lake sturgeon	7.77 (7.67-7.90) (N=85)	60	13.3 12.9-13.5) (N=13)	2.80 (2.42-3.24)

Tests conducted in 1994 agreed well with the results of previous tests. Sea lamprey larvae were about twice as sensitive as lake sturgeons (Table 1). Juvenile lake sturgeons tolerated concentrations of TFM between 1.2 and 1.3 times those producing 100% mortality of sea lamprey larvae (Table 2).

Laboratory Tests

The rainbow trout was the least sensitive species tested, followed by muskellunge and northern pike, and lake sturgeon (Table 3). The LC25s for these four fish species were well above the LC99.9 for sea lampreys produced under similar water chemistry parameters (Fig. 2).

Variation in water alkalinity from 30 to 215 mg/L as $CaCO_3$ did not appreciably affect the toxicity of TFM to any of the species tested. However, raising the pH from 7.2 to 8.2 significantly decreased the toxicity of TFM ($p \leq .05$). Raising the pH from 7.2 to 7.7, and from 7.7 to 8.2 produced significant differences in LC50 for both the rainbow trout and lake sturgeons. The 12-h LC50 for rainbow trout was 2.36 mg/L at pH 7.2 compared with 15.6 mg/L at pH 8.2 - one-sixth the toxicity. Likewise, the 12-h LC50 for the lake sturgeon was 0.93 mg/L at pH 7.2 compared with 3.50 mg/L at pH 8.2 - about one-fourth the toxicity (Fig. 3).

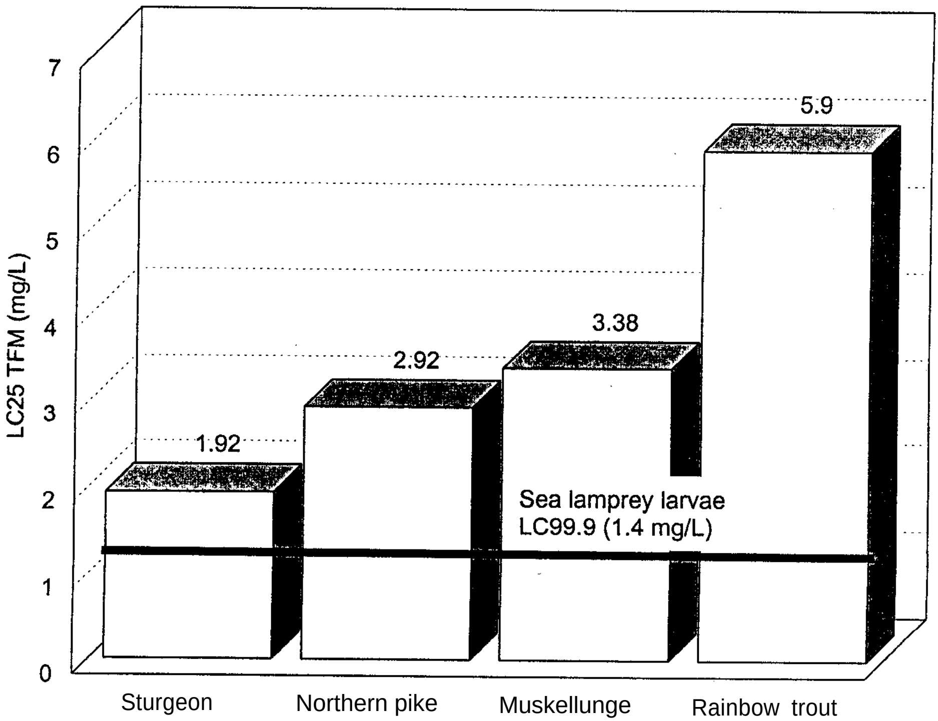

Figure 2. Sensitivity of four fish species exposed to TFM for 12 h in water of pH 7.7, total alkalinity 85 mg/L as $CaCO_3$, and temperature 12°C. Sensitivity is expressed as LC25 (mg/L) for nontarget fish compared with the LC99.9 for sea lamprey larvae.

Table 2. Mortality (%) of sea lamprey larvae and juvenile lake sturgeons exposed to TFM for 12 h in flow-through toxicity tests on the Sturgeon River, Baraga County, MI. Dashes mean no sea lamprey larvae or lake sturgeons tested at that TFM concentration.

Date	Mean TFM concentration (mg/L)	12-h sea lamprey mortality (%)	12-h lake sturgeon mortality (%)
August 30,1989			
	3.5	100	0
	2.6	100	0
	1.9	10	0
	1.4	0	0
	1.0	0	0
	Control	0	0
September 24, 1993			
	4.6	---	100
	3.7	---	80
	2.9	100	40
	2.4	100	0
	1.9	20	0
	1.2	0	0
	Control	0	0
September 26, 1993			
	4.4	100	100
	3.5	100	40
	2.8	100	20
	2.3	100	0
	1.8	80	0
	1.5	0	0
	1.2	0	0
	Control	0	0

Table 2 (continued)

Date	Mean TFM concentration (mg/L)	12-h sea lamprey mortality (%)	12-h lake sturgeon mortality (%)
October 6, 1994			
	4.1	---	100
	3.3	---	100
	2.7	---	90
	2.2	---	20
	1.7	100	0
	1.4	100	---
	1.2	0	---
	0.9	0	---
	0.7	0	---
	Control	0	0
October 8, 1994			
	3.9	---	100
	3.2	---	90
	2.6	---	30
	2.1	100	0
	1.7	100	0
	1.4	40	0
	1.1	0	---
	0.9	0	---
	0.7	0	---
	Control	0	0

Table 3. Toxicity of TFM (12-h LC25 and LC50, mg/L) to four fish species in laboratory flow-through tests under varying combinations of pH and alkalinity at 12°C. Intervals of 95% confidence are given in parentheses.

Species	PH	Alkalinity (mg/L as $CaCo_3$)	LC25	LC50
Lake sturgeon	7.7	30	1.49 (1.37-1.62)	1.58 (1.47-1.70)
Lake sturgeon	7.7	85	1.92 (1.82-2.02)	2.00 (1.91-2.09)
Lake sturgeon	7.7	215	1.81 (1.61-2.04)	1.95 (1.76-2.16)
Lake sturgeon	7.2	85	0.86 (0.76-0.97)	0.93 (0.84-1.02)
Lake sturgeon	8.2	85	3.15 (2.61-3.80)	3.50 (3.16-3.88)
Rainbow trout	7.7	30	6.48 (4.59-9.15)	7.60 (6.20-9.31)
Rainbow trout	7.7	85	5.90 (4.59-7.58)	6.66 (5.81-7.64)
Rainbow trout	7.7	215	5.99 (4.04-8.89)	7.00 (5.63-8.70)
Rainbow trout	7.2	85	2.24 (2.10-2.39)	2.36 (2.22-2.51)
Rainbow trout	8.2	85	14.2 (12.7-15.9)	15.6 (14.4-16.9)
Northern pike	7.7	85	2.92 (2.63-3.24)	3.09 (2.81-3.40)
Northern pike	7.7	215	2.98 (2.64-3.36)	3.17 (2.85-3.53)
Muskellunge	7.7	85	3.38 (3.10-3.68)	3.59 (3.33-3.87)
Muskellunge	7.7	215	2.81 (2.57-3.07)	3.02 (2.83-3.22)

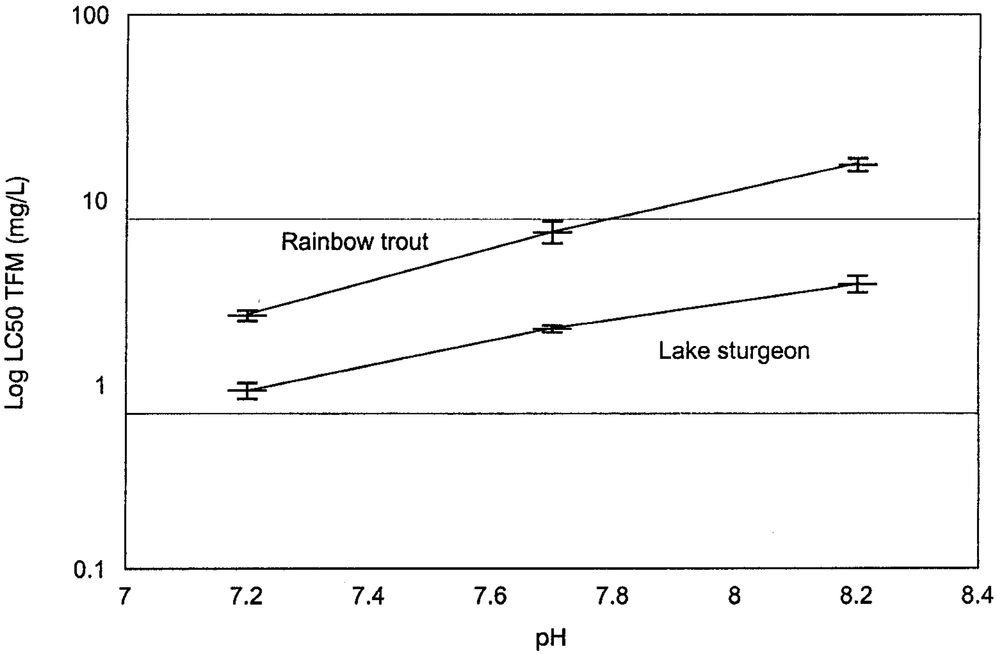

Figure 3. Response (LC50 and 95% confidence interval) of rainbow trout fry and juvenile lake sturgeons to exposures of TFM at pH 7.2, 7.7, and 8.2 in laboratory flow-through toxicity tests.

Post-Treatment Assessment

No dead adult or juvenile lake sturgeons were observed in the river or collected in the fyke nets after TFM treatments of the Sturgeon River in 1989 and 1994. Numerous dead sea lamprey larvae were collected or observed.

DISCUSSION

Although little information exists on the toxicity of chemicals to lake sturgeons, our data suggest their response is like that of other fish species to changes in water chemistry that affect toxicity. Bills et al. (1988) showed by static toxicity tests that pH is the primary factor affecting the toxicity of TFM and that changes in alkalinity have little effect. In our tests, the LC50 for TFM and juvenile lake sturgeons at pH levels of 7.2, 7.7, and 8.2 and at a single alkalinity showed about a 50% reduction in toxicity between pH 7.2 and 7.7, and about a 75% reduction between pH 7.2 and 8.2. This relation between pH and lake sturgeon mortality supports other previous studies on fishes (Dawson et al. 1975; Marking and Olson 1975; Bills and Johnson 1992) and suggests that lake sturgeon sensitivity to TFM is influenced, if not controlled, by pH.

We compared the LC99.9 for sea lampreys determined from our test with model regressions of LC99.9 for sea lamprey larvae developed for estimating actual treatment concentrations of TFM. The toxicity test results and model were similar when compared on the basis of total alkalinity and mean pH.

The power-generating facility at Prickett Dam (Fig. 1) controls the volume of water discharged into the lower Sturgeon River. Stream discharge is increased abruptly as power production is increased during peak generating periods. The changes in discharge cause significant changes in the water chemistry of the stream. In 1989, pH increased 5 h into the exposure period when stream discharge was reduced. This rise in pH allowed severely stressed lake sturgeons (dark in color and lacking equilibrium) exposed to 3.5 mg/L TFM to recover, and no mortality occurred during the remainder of the test. The increase in pH also slowed the progression of mortality in larval sea lampreys.

The 1989, on-site toxicity tests showed that TFM could be applied to the Sturgeon River without causing significant mortality of juvenile lake sturgeons. We used these results to select a treatment concentration of TFM that would kill sea lampreys but produce no significant mortality of juvenile lake sturgeons in the stream. As an additional safety measure, treatment was scheduled in the fall when juvenile lake sturgeons had migrated to lower reaches of the stream or into Lake Superior where dilution decreased TFM concentrations.

TFM is selective for sea lamprey larvae over lake sturgeons, but the difference in selectivity is less than that for most game fish species. The empirical difference between the estimated no effect (no mortality) concentration for lake sturgeon and the LC99.9 for sea lamprey larvae is about 1.3 to 1. Applying TFM at 1.3 times the concentration necessary to kill sea lamprey larvae provides sufficient allowance for dilution and other factors that decrease concentrations of TFM during most treatments while assuring a concentration lethal to a high percentage of sea lampreys throughout most of the treatment area. Although the difference in sensitivity of the two species is marginal, it is sufficient-when used with established application practices and techniques-to allow effective stream treatments with no significant mortality of juvenile and probably adult lake sturgeons.

Effects on lake sturgeon populations are further limited by several factors.

- Only a small number of streams support both spawning runs of the lake sturgeon and require treatment with TFM, and even these streams require infrequent applications of lampricide

- Streams suspected of supporting lake sturgeons are treated after young-of-the-year have time to outmigrate

- Juvenile lake sturgeons that have not left nursery streams probably would be in downstream areas where TFM concentrations are lowest

Concentrations of TFM decrease to near or even less than the sea lamprey LC99.9 in downstream reaches. Only lake sturgeons in areas near application points would be exposed to concentrations 1.3 times the

LC99.9 for sea lampreys. These factors suggest that opportunity for significant mortality of lake sturgeon during lampricide treatments is limited.

CONCLUSIONS

- Our data show that concentrations of TFM used for sea lamprey treatment can be about 1.3 times those concentrations needed to kill sea lampreys and still not produce significant mortality among juvenile lake sturgeons under water chemistry conditions similar to those in the Sturgeon River

- The toxicity of TFM to lake sturgeons relates strongly to pH- toxicity increases as pH decreases

- Lake sturgeons are more sensitive to TFM than rainbow trout, northern pike, and muskellunge

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