

Effects of Sea Lamprey (*Petromyzon marinus*) Control in the Great Lakes on Aquatic Plants, Invertebrates, and Amphibians¹

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GILDERHUS, P. A., AND B. G. H. JOHNSON. 1980. Effects of sea lamprey (*Petromyzon marinus*) control in the Great Lakes on aquatic plants, invertebrates, and amphibians. Can. J. Fish. Aquat. Sci. 37: 1895-1905.

The chemicals 3-trifluoromethyl-4-nitrophenol (TFM) or a combination of TFM and 2',5-dichloro-4'-nitrosalicylanilide (Bayer 73) have been used to control the sea lamprey (*Petromyzon marinus*) in the Great Lakes for about 20 yr. These chemicals cause some mortalities of Oligochaeta and Hirudinea, immature forms of Ephemeroptera (*Hexagenia* sp.), and certain Trichoptera, Simuliidae, and Amphibia (*Necturus* sp.). The combination of TFM and Bayer 73 may affect some Pelecypoda and Gastropoda, but its overall effects on invertebrates are probably less than those of TFM alone. Granular Bayer 73 is likely to induce mortalities among oligochaetes, microcrustaceans, chironomids, and pelecypods. No evidence exists that the lampricides have caused the catastrophic decline or disappearance of any species. The overall impact of chemical control of sea lampreys on aquatic communities has been minor compared with the benefits derived.

Key words: sea lamprey control, Great Lakes, TFM, Bayer 73, aquatic plants, invertebrates, amphibians

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Les substances chimiques 3-trifluorométhyl-4-nitrophénol (TFM) ou une combinaison de TFM et de 2',5-dichloro-4'-nitrosalicylanilide (Bayer 73) ont été utilisées dans le contrôle de la grande lamproie marine (*Petromyzon marinus*) dans les Grands Lacs pendant environ 20 ans. Ces substances causent une certaine mortalité chez les Oligochaeta et Hirudinea, les formes immatures d'Ephemeroptera (*Hexagenia* sp.) et certains Trichoptera, Simuliidae et Amphibia (*Necturus* sp.). La combinaison TFM et Bayer 73 peut affecter certains Pelecypoda et Gastropoda mais, dans l'ensemble, ses effets sur les invertébrés sont probablement moindres que ceux de TFM seul. Bayer 73 granuleux est susceptible de déclencher des mortalités parmi les oligochètes, microcrustacés, chironomides et pélecypodes. Nous n'avons pas de preuve que les lampricides ont causé le déclin ou la disparition catastrophiques d'aucune espèce. L'effet global du contrôle chimique de la grande lamproie marine sur les communautés aquatiques a été minime comparativement aux avantages qui en ont découlé.

Received October 19, 1979

Accepted March 31, 1980

Reçu le 19 octobre 1979

Accepté le 31 mars 1980

SEA lamprey control in tributaries of the Great Lakes began with installation of mechanical and electrical barriers (weirs) in the 1950s to block adult lampreys from their spawning grounds. The control of sea lampreys with chemicals began in 1958 with the application of 3-trifluoromethyl-4-nitrophenol (TFM) to tributary streams to kill the larval lampreys burrowed

in the stream bottom. In 1963, it was discovered that the addition of small amounts of 2',5-dichloro-4'-nitrosalicylanilide (Bayer 73) (up to 2%) significantly reduced the amount of TFM needed in stream treatments and similarly reduced the cost of treatment (Howell et al. 1964). Combinations of TFM and Bayer 73 have been used since 1963 for treatment of the larger tributaries of the Great Lakes. Most of the more than 400 tributaries found to harbor sea lampreys have been treated with either TFM or the mixture, and many have been treated several times in the 21-yr time span.

Early efforts at lamprey control were concentrated on the stream environments, but in the early 1960s, significant populations of ammocoetes were found to in-

¹This paper forms part of the Proceedings of the Sea Lamprey International Symposium (SLIS) convened at Northern Michigan University, Marquette, Michigan, July 30-August 8, 1979.

habit certain lentic areas in inland lakes and the Great Lakes near the mouths of lamprey-spawning streams. The lentic areas were difficult to survey, and collection efforts with bottom dredges or electric trawls did not reveal the full extent of these lentic populations. In 1966, a granular formulation of Bayer 73 (5% active ingredient) was shown to be an irritant that caused larval lampreys to leave their burrows and swim to the surface of the water where they could be collected (E. L. King Jr., and J. H. Howell, U.S. Bureau of Sport Fisheries and Wildlife, Great Lakes Fishery Laboratory, Administrative Report, 1970, mimeograph). This chemical technique provided better estimates of ammocoete populations and made it possible to survey lentic habitats effectively. Bayer 73 also acts as a lampricide and since 1966, many lentic areas in the Great Lakes drainage have been treated with the chemical.

Although the primary studies on lampricide chemicals were directed toward the development of efficient and effective methods to control lampreys, some studies have been made on the effects of the chemicals on other aquatic organisms.

The objective of this paper is to review the existing information on the effects of lampricides on plants, invertebrates, and amphibians in aquatic habitat and to provide an assessment of the observed and potential impact of lampricides on populations of these organisms.

TFM

STREAM TREATMENTS

The lampricide is applied at one or more points in a stream, depending on the extent of the stream system, the velocity and flow patterns, and the concentrations needed for effective control of lampreys in the particular stream. The amount of chemical applied at each point is that which will maintain a concentration lethal to lampreys to the next application point downstream, without exceeding the maximum concentration that is safe for salmonid fishes. Therefore the areas of the stream just downstream from application points are often exposed to much higher concentrations of the chemical than are some other areas farther downstream. The minimum effective and maximum allowable concentrations are usually 1–3 and 3–9 mg/L, respectively, in Lake Superior tributaries, and 2–8 and 6–16 mg/L, respectively, in tributaries to Lakes Michigan and Huron (Smith and Braem 1976).

FACTORS AFFECTING TOXICITY

The minimum effective concentration of TFM for control of sea lampreys varies considerably from stream to stream. In tributaries to Lake Huron treated in 1975, the minimum effective concentration ranged from 1.5 mg/L in the Carp River to 11.0 mg/L in the Pine River.

Dawson et al. (1975) demonstrated that temperature has little influence on the toxicity of TFM and that the

toxicity of the compound to larval sea lampreys decreases as pH and hardness of the water increase. Marking and Olson (1975) demonstrated that pH and hardness also affected the toxicity of TFM to bony fishes, but found that the toxicity of the chemical generally increased as water temperatures increased.

It has not been conclusively determined that the toxicity of TFM to plants and invertebrates is affected to the same degree by the same factors that affect the toxicity to sea lamprey larvae and other fish. Kawatski et al. (1975) showed that the toxicity of TFM to *Chironomus tentans* was decreased by high pH and hardness. Fremling (1975) showed a similar trend for *Hexagenia* mayflies and demonstrated a 60-fold decrease in toxicity between pH 6.5 and 9.5. Therefore, it appears that the relative toxicity of TFM to invertebrates follows approximately the same pattern from stream to stream as does the toxicity to lampreys, and that the safety index between invertebrates and lampreys is relatively constant. Concentrations of TFM in this paper are expressed as active ingredient, and the terms such as sensitive, resistant, and highly resistant are used to provide only general comparisons of the sensitivity of nontarget organisms with that of larval sea lampreys.

TYPES OF STUDIES

Numerous investigators have observed the effects of TFM on invertebrates in laboratory tests or in the field before and after stream treatments. Comparisons of results between investigators are difficult because laboratory tests were done in waters with widely different chemical characteristics, and few of the investigators included sea lamprey larvae in their tests. Thus it is difficult to establish the relative sensitivity of lampreys to that of other organisms in a particular type of water. Furthermore, field studies generally have not included enough replicate samples to lend statistical validity to the results. However, an examination of the overall data contributed by the several laboratory and field studies establishes trends and provides sufficient information on which to base certain conclusions.

The sources of data cited here as listed as (1) laboratory studies (also referred to as 24-h tests or LC50 values), (2) field studies, and (3) treatment summaries. The more comprehensive laboratory studies were done by Smith (1967) and Maki et al. (1975a), in which large numbers of organisms were exposed to TFM under relatively controlled conditions. In field studies, Torblaa (1968) sampled seven treated streams and two untreated streams, some for up to 6 wk after treatment and others up to 1 yr. Haas (1970) sampled before and 3–4 d after two separate treatments in a single stream. Treatment summaries consisted of notes and nonprecise estimates of mortality gleaned from summary sheets of past stream treatments done by the Ludington and Marquette Biological Stations in Michigan. The observations were summarized by lake basin

and by organism. If a treatment report did not contain observations on mortality of nontarget organisms, there was no way to determine whether there was any mortality, or whether any observations were made. Therefore, the percentage occurrence of mortality of any particular organism given represents the percentage of the total number of times mortality of any organism was recorded, not the percentage of times mortality occurred out of the total number of treatments done. For example, in Lake Superior tributaries, 37 treatment reports contained observations of mortality, and 17 of those, or 46%, included mayflies.

EFFECTS ON PLANTS

Maki et al. (1975b), who conducted laboratory tests on the effects of TFM on 10 species of algae in pure cultures, found that most species tested experienced a 50% inhibition of growth at less than 10 mg/L of active ingredient. Blue-green algae were generally most resistant (9–10 mg/L), green algae were intermediate (4–5 mg/L), and diatoms the most sensitive (1–3 mg/L). Concentrations of 30 mg/L did not destroy the viability of the cells, but temporarily inhibited growth. Tests in artificial streams showed that TFM inhibited community metabolism, reflecting in part, the effects on algal growth (Maki and Johnson 1976).

Although TFM does affect algal growth, and may temporarily inhibit stream productivity, rapid flushing of the chemical from the stream after treatment and the redistribution of unaffected algae from above the treatment site should limit adverse effects to short periods of time.

The effects of TFM on aquatic macrophytes can be severe at high concentrations, but appear to be low at concentrations used for sea lamprey control. Josephs (1961), who originally patented various salts of TFM as aquatic herbicides, presented evidence that TFM controlled common aquatic plants such as *Anacharis*, *Cabomba*, and *Ceratophyllum* at concentrations of 15–25 mg/L in standing water and 100 mg/L in flowing water.

In laboratory tests, Maki and Johnson (1977) showed TFM to inhibit growth of *Elodea canadensis* and *Myriophyllum spicatum* at concentrations of 10 mg/L and above in exposures of 1 h or more. The authors estimated that a treatment necessary to eliminate lampreys in the water they used could cause a 5–10% reduction in growth in *Elodea* and a 20% reduction in *Myriophyllum*.

Macrophytes are not abundant in lamprey-producing streams because such streams are generally fast flowing and have predominantly coarse bottom materials. Therefore, effects of TFM on aquatic plants will likely have little impact on productivity of the stream ecosystem.

EFFECTS ON INVERTEBRATES

Aquatic worms — Aquatic worms appear to be very

TABLE 1. Toxicity of field grade TFM (active ingredient) to selected macroinvertebrates in laboratory tests (data adapted from Maki et al. 1975a). Unless specified, insect nymphs and larvae were late instars.

Organism	Size (mm)	24-h LC50 (mg/L)	95% confidence interval (mg/L)
Pelecypoda			
<i>Pisidium</i> sp.	10–12	16.9	14.93–19.13
<i>Sphaerium</i> sp.	10–15	17.5	16.84–18.21
<i>Ligumia</i> sp.	<9	>11.2	—
<i>Ligumia</i> sp.	>16	>18.0	—
Isopoda			
<i>Asellus militaris</i>	8–10	17.0	14.41–20.06
Amphipoda			
<i>Gammarus pseudolimnaeus</i>	10–12	38.0	32.76–44.08
Decapoda			
<i>Orconectes propinquus</i>	30–40	>36.4	—
Ephemeroptera			
<i>Baetis</i> sp.		6.9	6.39–7.45
<i>Hexagenia bilineata</i>		7.9	6.93–9.01
<i>Cloeon</i> sp.		11.1	8.88–13.87
<i>Isonychia bicolor</i>		18.3	15.77–21.23
<i>Stenonema frontale</i>		24.9	22.23–27.89
<i>Tricorythodes</i> sp.		29.3	25.86–33.19
<i>Stenonema luteum</i>		29.6	27.92–31.37
<i>Paraleptophlebia</i>		>34.6	—
<i>Baetisca obesa</i>		37.8	33.16–43.09
<i>Ephemerella cornuta</i>	<4	36.2	31.75–41.27
<i>E. cornuta</i>	8	>39.0	—
Odonata			
<i>Ophiogomphus</i> sp.		>38.0	—
Plecoptera			
<i>Isoperla slossonae</i>		16.7	13.47–20.71
<i>Paragnetina media</i>		21.5	17.92–25.81
<i>Pteronarcys dorsata</i>		32.2	23.85–43.47
<i>Acroneuria lycorius</i>		>34.0	—
Megaloptera			
<i>Cauliodes</i> sp.		>36.0	—
Trichoptera			
<i>Chimarra obscura</i>		3.8	3.59–4.04
<i>Brachycentrus americanus</i>		10.5	8.40–13.13
<i>Lepidostoma</i> sp.		15.0	13.64–16.50
<i>Cheumatopsyche</i> sp.		28.3	24.71–32.40
<i>Hydropsyche</i> sp.		>32.0	—
<i>Macronemum</i> sp.		>38.0	—
<i>Limnephilus consocius</i>		>39.0	—
Diptera			
<i>Simulium pugetense</i>		6.1	5.65–6.59
Annelida			
Lumbricidae	60–90	6.6	6.11–7.13

sensitive to TFM. Smith (1967) showed 100% mortality of turbellarians at 8 mg/L in 24-h exposures, when sea lampreys were eliminated by 4 mg/L. Oligochaetes had 24-h LC50 values of 3.4–6.6 mg/L (Chandler and Marking 1975; Maki et al. 1975a; Table 1).

Maki et al. (1975a) stated that aquatic earthworms could be reduced by 50% or more by stream treatments. Treatment summaries showed some mortality of earthworms in 40% of the observations in Lake Superior tributaries and 23% in Lake Michigan tributaries, and some of those were interpreted as massive mortalities.

Crustaceans—Crustaceans appear to be very resistant to TFM (Table 1). Chandler and Marking (1975) determined the 24-h LC50 for TFM against *Daphnia magna* to be 26 mg/L. Smith (1967) observed only 2.7% mortality of isopods (*Asellus*) at 20 mg/L of TFM, and Maki et al. (1975a) recorded a 24-h LC50 of 17 mg/L for the same organism. Amphipods (*Gammarus* sp.) were found to be even more resistant by Maki et al. (1975a) and Sanders and Walsh (1975) who reported comparable 24-h LC50s of 38 and 36 mg/L, respectively. Smith (1967) observed only 10% mortality of these organisms in 24-h tests at 20 mg/L. In the field, Torblaa (1968) reported a decline in numbers of amphipods in two streams, and Maki (1974) noted a sharp rise in drift rates of amphipods in artificial streams tested with TFM. The declines observed by Torblaa (1968) may have been due to drift of amphipods out of the sampling areas, and not to actual mortality.

Crayfish apparently are the most resistant of the crustaceans; 24-h LC50s of 36–46 mg/L were reported by Maki et al. (1975a) and Sanders and Walsh (1975). No mortality of crayfish was noted in field studies, but light mortalities were recorded in 5% of the observations in treatment summaries from Lake Michigan tributaries and 13% of those from Lake Superior tributaries.

Laboratory and field data indicate that it is unlikely that significant mortality of crustaceans would be caused by concentrations of TFM used in stream treatments for sea lamprey control.

Aquatic insects—Larvae and nymphs of aquatic insects vary greatly in their sensitivities to TFM, ranging from very sensitive to highly resistant, even within a single order. Generally, among insects as among invertebrates as a whole, organisms with well-developed exoskeletons are the most resistant to TFM.

Three of the insect orders appear to be particularly resistant to TFM. Maki et al. (1975a) or Smith (1967) gave 24-h LC50s of 36 mg/L for Megaloptera, 38 mg/L for Odonata, and 20 mg/L for Hemiptera. Field studies also indicated no adverse effects on these organisms. However, mortality was noted for Odonata in up to 20% and Hemiptera in up to 10% of the observations recorded in treatment summaries.

Stoneflies (Plecoptera), as a group, are among the more resistant insects in laboratory tests (Table 1). Smith (1967) killed only 30% of those organisms at 12 mg/L and 76% at 20 mg/L. Torblaa (1968) found

a substantial decline in Nemouridae which persisted for several weeks in one stream, and Haas (1970) recorded a decline in *Taeniopteryx* in his study stream. Slight mortalities of stoneflies were noted in 13% (Lake Superior) to 19% (Lake Michigan) of the observations in treatment summaries. Overall, field data indicate only slight effects of TFM on stoneflies.

Mayflies (*Ephemeroptera*) have a wide range of resistance to TFM; some species are very susceptible and others highly resistant (Table 1). Maki et al. (1975a) stated that within a species, small sizes and early instars of mayflies are the most sensitive to TFM. Fremling (1975) found TFM to be most toxic to mayflies in water with a low pH and low total hardness.

Laboratory studies showed *Stenonema*, *Baetisca*, *Paraleptophlebia*, *Trichorythodes*, *Ephemerella*, *Callibaetis*, and *Isonychia* to be comparatively resistant to TFM, with 24-h LC50s ranging from 18 to 40 mg/L (Maki et al. 1975a; Chandler and Marking 1975). Smith (1967) reported similar findings for some of the same species. The mayflies found to be most sensitive in laboratory tests by Maki et al. (1975a) included *Cloeon*, *Baetis*, and *Hexagenia*. Smith (1967) showed 50% mortality of *Hexagenia* at 5 mg/L, and Fremling (1975) recorded 24-h LC50s for that genus ranging from 2.5 to 18.8 mg/L, depending on water hardness and pH. At pH 7.5 and lower, and at all water hardness tested, the 24-h LC50 was 7 mg/L or less. On the basis of their laboratory data, Maki et al. (1975a) and Fremling (1975) stated that concentrations of TFM used to control lampreys were likely to cause significant kills of mayflies.

Field studies by Torblaa (1968) and Haas (1970) each showed a trend toward reduced populations of mayflies, but none of the reductions appeared to be drastic. Torblaa (1968) recorded more sites at which there was no effect than sites at which a reduction was evident.

Mayflies (especially *Hexagenia*) were noted more often than any other organism among observations in treatment summaries. From 46 to 50% of the observations on invertebrates included dead mayflies, and in 17% of those in Lake Superior and 33% in Lake Michigan the numbers killed were large. Records of Canadian stream treatments also included occasional references to mortalities of mayflies. Several persons have reported what they interpreted to be premature emergence of mayflies during stream treatments (Applegate et al. 1961; R. Braem, Marquette Biological Station, Marquette, Michigan, personal communication). Maki et al. (1975a) documented this phenomenon in laboratory tests in which insect larvae exposed to TFM during late instar stages emerged as adults sooner than did the controls.

Caddis fly larvae (Trichoptera) also are variable in their sensitivity to TFM. Smith (1967), who differentiated between case building and net building caddis flies in his tests, noted an 8% mortality at 20

mg/L of TFM for 24 h for case builders and 44% for net builders. Maki et al. (1975a) demonstrated a 10-fold difference between their most sensitive and most resistant caddis fly larvae.

Torblaa (1968) recorded considerable declines (up to 94%) in numbers of caddis fly larvae in three of his study streams within 1 wk after treatment with TFM. Several other streams showed little or no change. Haas (1970) found declines in numbers of certain caddis flies in the Chocoy River after treatment.

The field treatment summaries indicate mortality of caddis flies in 30–33% of the observations, and about 10% of those involved large numbers. Thus, it appears that some species of caddis fly larvae are sensitive to TFM and subject to mortalities during stream treatments.

Coleoptera larvae were not included in any of the laboratory studies on toxicity of TFM. Torblaa (1968) found declines in Elmidae in three streams and an increase in one stream after treatment. The treatment summaries included beetle mortalities 5 and 17% of the time in Lake Superior and Lake Michigan tributaries, respectively. Beetles are not often a major component of the stream community or food chain, but they appear to be affected occasionally by stream treatments with TFM.

The Diptera appear to be resistant to TFM with the exception of black flies (Simuliidae). Both Smith (1967) and Maki et al. (1975a) found the 24-h LC50 for TFM to black flies to be 5–6 mg/L. Field samples taken by Torblaa (1968) included such small numbers of black flies that no conclusions could be drawn. None of the treatment summaries included observations on black flies, probably because the larvae are small, dark-colored, and soft-bodied, and therefore easily overlooked.

Snipe fly larvae (Rhagionidae) were found to be resistant by Smith (1967), who reported no mortality among larvae held in 20 mg/L of TFM for 24 h. Field studies by Torblaa (1968) and Haas (1970) showed no significant effects on this group.

Chironomids also are resistant to TFM; Smith (1967) reported a 24-h LC50 of more than 20 mg/L. Kawatski et al. (1975), who tested *Chironomus* in the laboratory, found the larvae to be immobilized by concentrations of 1–10 mg/L of TFM. However, most individuals recovered when placed in freshwater. Torblaa (1968) and Haas (1970) found rather drastic reductions in numbers of chironomids in some treated streams, but noted similar concurrent decreases in control streams, suggesting natural emergence as the cause.

Numbers of Tipulidae and Heleidae were reduced in some treated streams, but not in others (Torblaa 1968). Dead tipulids were noted in up to 30% of the observations in treatment summaries, but the numbers were always small. Laboratory data on these groups are not available.

Although certain species are sensitive to TFM, mor-

talities of dipterans does not appear to be a widespread or serious side effect of TFM treatments.

Molluscs — Molluscs exhibited intermediate resistance to TFM in laboratory tests. The 24-h LC50 values for snails (*Physa*) were more than 20 mg/L (Smith 1967). Unionid clams were slightly less resistant with LC50s of 10 mg/L (Smith 1967) to 17.5 mg/L (Maki et al. 1975a). Molluscs were rare in the field studies by Torblaa (1968), and no strong trend was observed. In the stream treatment summaries, dead snails were noted in up to 11% of the observations and clams in up to 21%.

There were occasional reports of distressed clams with gaping valves during treatments with TFM in Canadian streams, but most recovered after the bolt of chemical passed. It appears that although molluscs are sometimes killed by stream treatments with TFM, populations are not decimated.

EFFECTS ON VERTEBRATES

Amphibians are the only vertebrates besides fish which have been observed to be affected by lampricides. No laboratory or field study data are known to be available on these organisms. However, field treatment summaries often referred to amphibians. Mortality of frog tadpoles was noted in 16% of the observations, and one observation referred to large numbers of dead tadpoles. Mud puppies (mostly *Necturus*) were noted in 32% of the observations in tributaries of Lake Superior and 36% in Lake Michigan, and up to 18% of those referenced large numbers killed. Mortalities of these amphibians are evidently common during stream treatments with TFM.

OVERALL EFFECTS OF TFM TREATMENTS

Available data on TFM from both laboratory tests and stream treatments indicate that some organisms are likely to be killed during any particular stream treatment. Those most likely to be affected include turbellarians, oligochaetes, leeches, mayflies (especially *Hexagenia*), some species of caddis flies, black flies, and mud puppies. Others which may be affected are beetle larvae (especially Elmidae), crane fly larvae, stoneflies, and clams. Kills of aquatic annelids and mayflies may involve substantial numbers during some treatments. Maki et al. (1975a) estimated that under conditions of their tests, aquatic earthworms, black fly larvae, and certain mayfly and caddis fly larvae could be reduced by 50% or more. Some studies indicate a temporary decrease in gross primary production (Maki and Johnson 1976) and significant reductions in density (numbers) of organisms (Maki 1974; Maki et al. 1975c). Maki (1974), however, found that TFM did not affect the diversity of organisms in artificial stream communities. Several groups appearing to be highly

resistant in laboratory toxicity tests but showing some mortality in field observations were probably killed by high concentrations of TFM immediately downstream from application sites.

The effects of TFM on the nontarget portion of the stream community do not appear to be long lasting. Maki and Johnson (1976) found that community metabolism returned to normal within 24–36 h after treatment. Numbers of organisms had recovered by 4 wk to 3 mo after treatment in studies by Maki et al. (1975c) and Maki (1974). Torblaa (1968) found that numbers of organisms in most of his study streams recovered within 6 wk after treatment. Although some species of invertebrates may be substantially reduced in numbers by stream treatments with TFM, it is doubtful that the total biomass of food organisms would be reduced enough to affect the nontarget fishes appreciably.

TFM–Bayer 73

STREAM TREATMENTS

The combination of TFM and Bayer 73 (commonly called TFM-2B) has been used since 1963 for the treatment of some streams. Bayer 73 is used in a wettable powder with 70% active ingredient. Smith et al. (1974) report that the amount of Bayer 73 applied is usually 1–2% of the amount of TFM applied, and that this generally reduces the amount of TFM needed by about 50%. The use of Bayer 73 with TFM complicates both the logistics of a stream treatment and the analysis for lampricides. Bayer 73 is also more difficult to apply because of its low solubility and tendency to plug small pumps. Consequently, use of the combination is generally restricted to large rivers where a substantial saving in the amount of chemical needed offsets the added difficulty of the treatment. Bayer 73 is usually added to a stream at the same site or sites as TFM, but in some past treatments, Bayer 73 was added at a point downstream from the TFM application site to boost the activity of TFM already in the stream.

FACTORS AFFECTING TOXICITY

Toxicity of TFM-2B follows approximately the same pattern as that of TFM alone. Water temperature does not significantly affect toxicity of TFM-2B to fish (Dawson et al. 1977). Dawson et al. (1977) also found no significant effect of water hardness on the toxicity of the combination, but Howell et al. (1964) reported TFM-2B to be more toxic in soft water with low pH than in harder water with higher pH. Probably in the tests by Howell et al. (1964), pH was the influencing factor, but the two factors were not isolated in the test procedure. Dawson et al. (1977) found that high pHs decreased the toxicity of TFM-2B to larval sea lampreys.

The addition of Bayer 73 to TFM results in greater increases in toxicity to sea lampreys than to most of

TABLE 2. Safety indices for selected nontarget organisms when exposed to the lampricides TFM and TFM-2B in laboratory tests.

Organism	Safety index ^a	
	TFM ^b	TFM-2B ^c
Gastropoda <i>Physa</i> sp.	>11	2.5
Pelecypoda	4.0	6.0
Turbellaria	1.9	1.9
Hirudinea	3.9	5.1
Plecoptera	10.7	19.7
Ephemeroptera <i>Hexagenia</i> sp.	2.8	5.1
Simuliidae	2.8	4.4

^aTwenty-four-hour LC50 for nontarget organism/24-h LC50 for larval sea lamprey.

^bEstimated from the data of Smith (1967).

^cCalculated from the data of Rye and King (1976).

the invertebrates for which laboratory data are available. The safety index (LC50 for invertebrate/LC50 for sea lampreys) for most invertebrates tested is slightly greater for TFM-2B than for TFM alone (Table 2).

TYPES OF STUDIES

Studies on effects of TFM-2B have been much more limited than those with TFM alone. Rye and King (1976) conducted laboratory bioassays with TFM-2B against a variety of invertebrate organisms (Table 3). Inasmuch as this study was conducted in the same facility with the same water source as the tests with TFM conducted by Smith (1967), these two studies provide the best available data for comparison of the toxicities of the two lampricides to invertebrates.

Sampling by Torblaa (1968) in one stream treated with the combination provided the only field data on the effects of TFM-2B on invertebrates. Three Mile Creek was treated with 5 mg/L of the combination (4.9 mg/L TFM:0.1 mg/L Bayer 73). Treatment summaries on effects of TFM-2B on nontarget organisms were scant because the combination was used in only a small percentage of treatments, and observations have not been routinely recorded in recent years.

EFFECTS ON INVERTEBRATES

Aquatic worms — Laboratory tests show turbellarians to be sensitive to TFM-2B (Rye and King 1976; Table 3) and to have the same safety factor as with TFM alone (Table 2). Aquatic annelids are also sensitive to the combination with 24-h LC50 values ranging from 2.2 mg/L for *Tubifex* to 5.2 mg/L for *Lumbriculus* (Rye and King 1976). The laboratory toxicity data indicate that all of the groups of aquatic worms are probably susceptible to mortalities during stream treatments. Torblaa (1968) noted a reduction in annelids from 3 to 0 per square foot (0.092 m²), but

TABLE 3. Toxicity of TFM-2B (98% TFM and 2% Bayer 73) and Bayer 73 to selected macroinvertebrates and larval sea lampreys in laboratory tests. (Data adapted from Rye and King 1976.)

Organism	24-h LC50 and 95% confidence interval (mg/L)	
	TFM-2B	Bayer 73
Gastropoda		
<i>Physa</i> sp.	1.93 (1.54-2.41)	0.106 (0.097-0.116)
<i>Pleurocera</i> sp.	9.4 (7.74-11.4)	0.335 (0.290-0.430)
Pelecypoda		
<i>Elliptio dilatatus</i>	4.7 (3.5-6.3)	0.382 (0.320-0.458)
Turbellaria		
<i>Dugesia tigrina</i>	1.5 (1.42-1.58)	0.048 (0.044-0.053)
Oligochaeta		
<i>Tubifex tubifex</i>	2.25 (1.98-2.55)	0.034 (0.031-0.037)
<i>Lumbriculus inconstans</i>	5.2 (4.8-5.6)	0.14 (0.12-0.18)
Hirudinea		
Eropobdellidae	4.0 (3.3-4.9)	0.42 (0.38-0.47)
Cladocera		
<i>Daphnia pulex</i>	7.35 (5.74-9.41)	0.8 (0.68-0.94)
Isopoda		
<i>Asellus militaris</i>	31.0 (28.7-33.5)	23.0 (18.4-28.8)
Amphipoda		
<i>Gammarus</i> sp.	26.0 (24.4-27.7)	2.6 (2.34-2.88)
Decapoda		
<i>Orconectes</i> sp.	> 100	> 50
Ephemeroptera		
<i>Hexagenia</i> sp.	4.0 (3.6-4.5)	6.9 (5.85-8.14)
<i>Stenonema</i> sp.	30.5 (26.1-35.7)	2.27 (1.68-3.08)
Odonata		
<i>Ophiogomphus</i> sp.	> 100	> 50
Plecoptera		
<i>Paragnetina</i> sp.	15.4 (12.4-19.0)	1.07 (0.79-1.44)
Hemiptera		
Corixidae	40.0 (32.8-48.8)	> 50
Megaloptera		
<i>Corydalus</i> sp.	> 100	> 50
Trichoptera		
<i>Hydropsyche</i> sp.	30.0 (25.6-35.1)	2.45 (1.88-3.19)
<i>Helicopsyche</i> sp.	48.0 (38.1-60.5)	1.67 (1.18-2.37)

TABLE 3 (Concluded)

Organism	24-h LC50 and 95% confidence interval (mg/L)	
	TFM-2B	Bayer 73
Diptera		
<i>Simulium</i> sp.	3.45 (3.05-3.89)	0.255 (0.236-0.275)
<i>Atherix</i> sp.	> 100	> 50
Cyclostomata		
<i>Petromyzon marinus</i>	0.78 (0.684-0.889)	0.049 (0.043-0.056)

the very small numbers do not permit conclusions. Dead leeches were noted in the treatment summary of one stream treated with the combination.

Crustaceans — The cladoceran *Daphnia pulex* was moderately sensitive to the combined lampricides. A safety factor of 9.4 in comparison to that of larval lampreys indicates that *Daphnia* would rarely be subjected to lethal concentrations.

Macrocrustaceans were highly resistant to the combination in laboratory tests; 24-h LC50s ranged from 26 mg/L for amphipods to over 100 mg/L for crayfish (Table 3). In Three Mile Creek, Torblaa (1968) observed a 49% reduction in amphipod numbers 1 wk after treatment. Considering the laboratory LC50 of 26 mg/L, the apparent reduction was more likely due to sampling variation or drift than to mortality.

Aquatic insects — Aquatic insects follow a pattern of sensitivity to TFM-2B similar to that of TFM alone, although a comparison of laboratory studies by Rye and King (1976) and Maki et al. (1975a) showed that fewer insects are likely to be affected by TFM-2B. Rye and King (1976) showed that burrowing mayflies and black flies were the only organisms likely to be affected by stream treatments with TFM-2B. Numbers of these organisms in the field samples taken by Torblaa (1968) were too small to permit conclusions. Torblaa (1968) showed a 94% reduction in numbers of caddis flies of the family Psychomyiidae. Since the number of species within families were limited in the tests by Rye and King (1976), some sensitive species may exist within generally resistant families as was shown for TFM by Maki et al. (1975a). The safety indices for mayflies and black flies are 4-5 (Table 2), while those for other insects tested are over 19, indicating that few taxa of insects are likely to be exposed to lethal concentrations of TFM-2B.

Molluscs — Published data on the effects of TFM-2B on molluscs are limited to laboratory tests of two genera of snails and one of clams (Rye and King 1976). *Physa* is very sensitive but *Pleurocera* is more resistant and not likely to be affected by stream treatments (Table 3).

The clam *Elliptio dilatatus* was quite sensitive to the combination (Table 3); however, no mortalities of clams have been reported in streams treated with TFM-2B.

EFFECTS ON VERTEBRATES

No quantitative data are available on the effects of TFM-2B on aquatic vertebrates other than fish. The treatment summaries for the Tahquamenon River (Michigan) included observations on dead mud puppies in 3 different years. Since mortalities of mud puppies are common in streams treated with TFM alone, a similar frequency of mortalities is probable with TFM-2B.

OVERALL EFFECTS OF TFM-2B TREATMENTS

Only limited data are available on effects of TFM-2B on invertebrates. The laboratory test data indicate that aquatic worms (turbellarians and annelids), burrowing mayfly nymphs, black fly larvae, some snails, and some clams are likely to be affected. In addition, field observations show mortalities of mud puppies. The overall effects of treatments with TFM-2B on invertebrates are probably less than those with TFM alone, because the addition of Bayer 73 to TFM increased the toxicity to sea lampreys to a greater degree than for most invertebrates.

Granular Bayer 73

TREATMENTS

Granular Bayer 73 (5% active ingredient) is used to treat populations of larval lampreys in lentic areas near the mouths of streams in which sea lampreys spawn. The material is applied to areas up to several hectares in size with a gasoline-powered blower or a cyclone-type spreader, usually from a boat. Amounts of the formulation used are usually 112–168 kg/ha (100–150 lb/acre) in the United States and 224 kg/ha in Canada. Such applications are intended to deliver a theoretical concentration of active ingredient in the bottom 5 cm of water of 11.5–17.2 mg/L in U.S. treatments and 23 mg/L in Canadian treatments. However, laboratory tests have shown that even under ideal conditions of temperature and pH of the water, less than 40% of the active ingredient is released over a period of 24 h (U.S. Fish and Wildlife Service, National Fishery Research Laboratory, La Crosse, Wisconsin, unpublished data). Usually within an hour after application, larval lampreys emerge from their burrows in the bottom sediments and swim to the surface of the water, where they can be observed or collected. Some measure of control is accomplished during such surveys because many of the larvae have received a lethal dose by the time they leave their burrows (Tibbles 1967).

FACTORS AFFECTING TOXICITY

Dawson et al. (1977) conducted laboratory tests on Bayer 73 under varied water conditions using both larval sea lampreys and fish as test organisms. They found a slight reduction in toxicity at lower temperatures. Field application crews have reported that the time required for the chemical to drive lampreys to the surface is much increased at temperatures below 10°C. Water hardness had no measurable effect on toxicity over a range of 44–800 mg/L total hardness. Dawson et al. (1977) found that Bayer 73 was somewhat more toxic at low pH than at high pH, but this effect was not great over the range of pH found in most of the lamprey-producing waters (7.5–8.5). The general conclusion indicated by laboratory tests on fish is that water chemistry has little effect on the toxicity of the chemical. Tests on invertebrates have not included variations in water chemistry.

TYPES OF STUDIES

Bayer 73 has been studied and used as a control for snail vectors of schistosomiasis in tropical countries and for control of larval sea lampreys in the U.S. Laboratory and field studies have been conducted in the tropical countries on the effects of Bayer 73 on snails and nontarget invertebrates. In the U.S., small-scale laboratory tests have been done with algae (Farringer 1972) and aquatic invertebrates (Sanders 1977). Rye and King (1976) did a comprehensive laboratory study which included larval lampreys for comparison with invertebrates (Table 3).

Laboratory studies that establish 24-h LC50s, however, do not necessarily approximate the effects of Bayer 73 as it is used in lamprey surveys. The treatments are designed to establish a high concentration for a brief period of time with the assumption that the chemical will quickly be diluted by the surrounding water. Field observations indicate that the activity of the chemical usually lasts less than 2 h against larval lampreys.

Effects of Bayer 73 on invertebrates under natural conditions were assessed by personnel at Hammond Bay Biological Station, Millersburg, Michigan (unpublished data) in treatment of a small plot in the Ocqueoc River (Michigan) at a rate of 18.8 kg/ha (active ingredient). Only one quantitative field study of the effects of granular Bayer 73 on invertebrates in lentic areas has been done (Gilderhus 1979). In that study, samples were taken up to 13 d after treatment of a 0.8-ha plot in Boardman Lake (Michigan) at a concentration of 11.5 mg/L in the bottom 5 cm of water.

EFFECTS ON PLANTS

Farringer (1972) found that high concentrations (50 mg/L) of Bayer 73 affected algae (*Chlamydomonas* and *Chlorella*) by reducing their growth by 50% over

a period of 8 d. Interpolation of these results to the much lower concentrations and shorter exposure times required in lamprey surveys indicates that little effect on algae would be expected in treatment of lentic areas. Schiff and Garnett (1961) observed a severe setback of *Chara* by 1 mg/L of Bayer 73 in ponds. In contrast, Abdalla and Nasr (1961) found that concentrations up to 5 mg/L did not harm aquatic vegetation. Considering the type of treatment used in the lamprey control program, it is unlikely that vegetation would be noticeably affected.

EFFECTS ON INVERTEBRATES

Aquatic worms — Rye and King (1976) showed that aquatic worms are very sensitive to Bayer 73 at concentrations far below those used in lentic habitat (Table 3). As expected in the field, numbers of oligochaetes and leeches were reduced by 80–90% after treatment (Gilderhus 1979).

Crustaceans — Microcrustaceans are very sensitive to Bayer 73. Pond studies showed reductions of cladocera, copepods, and ostracods after treatments at 1 mg/L, but populations returned to normal within 32 d (Schiff and Garnett 1961). An LC₅₀ of 23 mg/L for isopods (Rye and King 1976) indicates that they are not likely to be affected by field treatments. Amphipods are more sensitive; published 24-h LC₅₀s have ranged from 2.6 mg/L (Rye and King 1976) to 5.6 mg/L (Sanders 1977). Considering the low LC₅₀ values for amphipods, some mortality would be expected from field use of Bayer 73. However, there was no reduction in the substantial population of amphipods present in the study by Gilderhus (1979).

Crayfish are highly resistant, having 24-h LC₅₀ values of 32 mg/L (Sanders 1977) to over 50 mg/L (Rye and King 1976).

Aquatic insects — Aquatic insects vary greatly in their resistance to Bayer 73. Some, such as dragonfly nymphs, water boatmen, snipe fly larvae, and dobsonfly larvae are highly resistant; 24-h LC₅₀s exceed 50 mg/L (Rye and King 1976). Others, including some of the important fish food groups, have 24-h LC₅₀ values in the range of 1–10 mg/L. Laboratory LC₅₀ data cannot be easily used to estimate effects in the field because in operational treatments the organisms are exposed to much higher concentrations for much shorter periods of time.

Stonefly nymphs are sensitive to Bayer 73; 24-h LC₅₀s range from 1.1 to 2.3 mg/L (Sanders and Cope 1968; Rye and King 1976). However, stoneflies are not likely to be present in lentic habitats.

Mayfly nymphs were moderately sensitive in laboratory tests (Table 3). King (1974) listed an LC₅₀ for mayflies of 11.4 mg/L. No effect was found on a substantial population of mayflies following a field treatment of 11.5 mg/L (Gilderhus 1979).

Caddis flies also were sensitive to Bayer 73 in laboratory tests (Table 3). An experimental treatment in the Ocqueoc River reduced the caddis fly larvae population by about 90% (Hammond Bay Biological Station, unpublished data). The treatment in Boardman Lake showed a 40% reduction in numbers of caddis fly larvae at 7 d after treatment (Gilderhus 1979).

Beetle larvae were not included in any laboratory tests and no field data are available.

In contrast to snipe flies, some of the Diptera are very sensitive to Bayer 73. Black flies (Table 3) were virtually eliminated by an 18.8 kg/ha treatment in the Ocqueoc River (Hammond Bay Biological Station, unpublished data). However, black flies are not likely to inhabit the lentic areas treated with granular Bayer 73.

Midge larvae (*Chironomus*) are also sensitive. Kawatski et al. (1975) showed that 50% of the organisms were immobilized by 0.6–0.8 mg/L in 24-h laboratory tests. Gilderhus (1979) found that numbers of midge larvae were reduced by a statistically significant 54% at 7 d after treatment in Boardman Lake.

Molluscs — Molluscs are very sensitive to Bayer 73 (Table 3). Abdalla and Nasr (1961) killed all snails (*Bulinus*) with 1 mg/L in 4 h and 2 mg/L in 2 h in laboratory tests. In field applications in Egypt, Abdalla and Nasr (1961) found that applications of 1 mg/L for 5 h gave 100% control of snails (*Bulinus* and *Biomphalaria*) in standing water, and 1 mg/L for 8 h gave complete control in flowing water. Harrison (1966) reported that blanket spraying of two streams in Rhodesia at 0.2–0.4 mg/L of Bayer 73 killed all snails. After the lamprey treatment in Boardman Lake, Gilderhus (1979) found that snails were essentially unaffected even though the theoretical concentration was much higher than that required to kill snails elsewhere.

Clams are as sensitive as snails in laboratory tests (Table 3) and apparently are more sensitive under field conditions. The plot treatment in the Ocqueoc River reduced the numbers of clams (Hammond Bay Biological Station, unpublished data), and Gilderhus (1979) found a 62% reduction in numbers of clams by 7 d after treatment in Boardman Lake.

Considering the extreme sensitivity of molluscs to Bayer 73 in laboratory tests, adverse effects of field treatments on molluscs were less than expected.

OVERALL EFFECTS OF BAYER 73 TREATMENTS

Effects of Bayer 73 treatments on nontarget organisms in the field were generally less than expected. Aquatic worms (Oligochaeta) and midge larvae were the most sensitive, and significant short-term declines in their populations can be expected. Moderate declines can be expected in numbers of microcrustaceans and molluscs (especially clams). Other organisms, such as amphipods and mayflies, were not affected by the field

treatment studied, but may be subject to mortalities from some treatments.

Considering that the use of Bayer 73 for survey or control of sea lamprey larvae in lentic habitat will involve only a small percentage of any body of water, the effects on invertebrate populations are expected to be minor.

Summary and Discussion

The studies done on the effect of TFM treatments in streams have included a variety of laboratory and field assessments which help evaluate the real and potential impact of this chemical on nontarget organisms. The effects of TFM-2B on invertebrates in laboratory tests seem to be less than those of TFM, but a comprehensive stream study would be needed for confirmation. Work on Bayer 73 for treatment of lentic habitats has not been extensive, but is probably adequate to estimate potential effects in many treatments. However, in the only field study done to date, the treatment rate was 112 kg/ha of the granular formulation, whereas up to twice that amount is used in Canadian treatments. Further field study would be needed to assess adequately effects of higher treatment rates on nontarget organisms.

Maki et al. (1975a) observed that early life stages of some invertebrates were more sensitive than later stages, and species with well developed exoskeletons were most resistant to TFM. Laboratory toxicity tests done on specimens collected in the field and field observations have probably been heavily weighted toward larger specimens or relatively mature life stages. Therefore the available data may underestimate the effect of lampricides on some invertebrates.

The overall impact of lampricides on invertebrates has probably been of minor importance in aquatic ecosystems. Although significant mortalities of some fish food organisms may occur, they are usually confined to small segments of a particular stream system, and other important food organisms are left unaffected. No evidence exists to indicate that a species has been totally eliminated from a stream. In nearly all streams and lakes treated for lampreys, a portion of the system remains untreated to provide organisms for recolonization of the treated area.

The use of almost any toxicant for the control of a pest organism involves nontarget organisms to some degree. The user must therefore evaluate the impact on the ecosystem against the benefit derived from control of the pest or predator organism. The occasional kills of certain nontarget organisms appear insignificant in comparison with the benefit that sea lamprey control affords the fish populations of the Great Lakes.

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