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March 1970

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CONTROL OF FRESHWATER FISH WITH CHEMICALS

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ABSTRACT: Fish toxicants have been used for nearly 60 years by sport fishery managers to remove predaceous or competing fishes from gamefish waters. The reclamation of lakes and streams by poisoning unwanted fish is considered to be one of the better management tools, and the demand for reclamations is increasing as more waters come under intensive management. Many chemicals have been tried as fish toxicants, but the insecticides rotenone and toxaphene have been most widely used despite their disadvantages of non-selectivity between wanted and unwanted fishes, persistence in water, and toxic effects on aquatic invertebrates. Research in the past 20 years led to the development of toxicants specific to fish and formulations better suited to aquatic applications. Further progress is noted in the search for safe, more selective controls for pest fishes in the wide variety of aquatic environments.

FISH IN PEST SITUATIONS

Pest situations involving freshwater fish are numerous and widespread. Most of them have resulted directly or indirectly from man's altering the composition of fish populations or changing the aquatic ecosystem. We dug canals, channeled streams, dammed rivers, drained marshes, and polluted surface and subsurface waters. We selectively exploited some fishes over others for sport, food, or industrial purposes. We stock millions of fish each year in warm and cold, fresh and marine waters. We know that many cultured fishes prosper in wild waters only if relieved of competition or predation from native fishes. Thus, we have long sought to promote some fishes and to control or eliminate others.

The destructive sea lamprey (Petromyzon marinus), for example, gained access to the upper Great Lakes via the Welland Ship Canal that was built in Canada in 1829 to bypass Niagara Falls (Baldwin, 1968). The alewife (Pomolobus pseudoharengus), an anadromous native of the North Atlantic, also invaded the upper Great Lakes via the Welland Canal and exploded to super-abundance once the larger carnivorous fishes were destroyed by sea lampreys. Chicago and other cities have experienced water shortages within recent years because dense schools of alewives sometimes block water intake lines in Lake Michigan, necessitating control measures. In periodic die-offs, millions of alewives befoul American and Canadian shorelines.

The home-aquarist and the bait-fish trades helped to establish the goldfish (Carassius auratus) in many American waters. Wild goldfish by abundance and habits are often as undesirable as carp (Cyprinus carpio). The walking catfish (Clarias batrachus) reportedly escaped from a tropical fish dealer in Florida and is now reproducing successfully in wild waters (idyll, 1969). Piranha (Serrasalmus sp.) thrive in new hydroelectric impoundments in Brazil and pose a great threat to livestock and people, especially fishermen, unless controlled by toxicants (Fontenele, 1963).

Some prized food and game fishes have become intermediate hosts for parasites dangerous to man because of water pollution. The parasites include fish tapeworm (Diphyllobothrium latum), intestinal fluke (Clonorchis sinensis), liver fluke (Opisthorchls felineus), and others (Bauer, 1961; and Van Duijn, 1962). Improved sanitation and eradication of infected fish are among measures proposed for control of helminthoses in fish-culture ponds.

But it is through fish stocking that man creates most of the pest-fish situations for himself. His predilection for importing exotic species and transplanting natives was boosted in the 19th century by the advent of fish hatcheries and rapid transportation. Many introductions are successful; many are not. In Russia, 2,467 introductions of commercial fishes were made in 1,398 bodies of water between 1763 and 1957, and the desired results were achieved in only one of 20 cases on the average (Burmakin, 1965). Trout and salmon got new homes throughout the world, and benefits appear to outweigh the problems. Recently, coho and chinook salmons (*Oncorhynchus kisutch* and *O. tshawytscha*) were introduced in the Great Lakes.

The introduction of carp into the United States from Germany less than 100 years ago to provide food and sport was at first hailed as a triumph (Laycock, 1966). It occurs in the 48 contiguous states; and it is probably more abundant than any other freshwater fish. But, its popularity waned quickly, and the carp is now the principal pest-fish in the U.S.

and the target of many fish-control efforts. Because of its abundance, large size, and rooting feeding habit, the carp causes troublesome turbidities, disturbs or destroys aquatic vegetation of importance to waterfowl, and adversely affects fish habitat and fishing economy (Sigler, 1958; and Gottschalk, 1967). Despite this, it would be folly to say that the carp is all bad, and there are indications that it is regaining some measure of favor with fishermen in local situations.

When introduced into Cuba, our largemouth bass (Micropterus salmoides) preyed too heavily on the native cyprinodont fishes that are important in malaria control. In Guatemala, the largemouth wrecked the freshwater crab fishery in Lake Atitlan and then proceeded to prey on the young of the rare and flightless, giant pied-billed grebe (Podilymbus gigas) (Powers and Bowes, 1967). The bass has also been a problem-predator on valued native fishes in South America.

The expanding mono-species culture of fish and shellfish incurs problems with indigenous competitor or predator fishes. Predaceous fish are controlled by toxicants in shrimp-culture ponds (Tang, 1961), and in fish-culture ponds in Japan and Malaya (Soong and Merican, 1958). Competing fishes are eliminated by toxicants from channel catfish (Ictalurus lacustris) ponds. And, green sunfish (Lepomis cyanellus) and bluegill (Lepomis macrochirus) often need thinning or complete removal in farm and ranch ponds.

There are many "natural" circumstances where chain pickerel (Esox niger), northern pike (Esox lucius), white sucker (Catostomus commersoni), California roach (Herperoleucus symrnetricus) and other minnows (Cyprinidae), bullheads (Ictalurus spp.), and yellow perch (Perca flavescens) are targets for control in trout lakes. Squawfishes (Ptychocheilus spp.) and freshwater sculpins (Cottus spp.) are controlled in some West Coast waters because of predation on young salmon. Gars (Lepisosteus spp.), bowfin (Amia calva), gizzard shad (PoroSoma cepedianum), and carp are commonly controlled in warmwater fisheries.

The preceding is a sketchy resume of factors contributing to and species involved in pest-fish situations. The trend is toward more man-fish conflicts because of the increasingly intensive use of surface waters for multiple purposes.

RECLAMATION OF LAKES AND STREAMS

In a review of fish toxicants, Prevost (1960) stated that the rehabilitation of waters by poisoning fish is the best available management tool. Complete statistics are not available, however, on the numbers of ponds, lakes, and streams that have been treated with poisons. Possibly thousands of the two million farm and ranch ponds in private ownership in the United States are renovated annually. Conservation agencies in 49 states, excluding Hawaii, reclaimed over three-quarters of a million acres of lakes and streams through 1965 to improve fishing (Stroud and Martin, 1968). In Canada, seven provinces have poisoned lakes, principally to improve trout fishing. Food-fish ponds are routinely treated with toxicants in Germany, Russia, and Asia.

It is difficult to evaluate the long-term results of reclamations. Complete elimination of undesirable fish is the exception rather than the rule in larger lakes and streams. States have reported that good fishing prevailed for 3 to 10 years, averaging 7 years, following reclamation of coldwater lakes, and for 1 to 15 years, averaging 5 years, in warmwater lakes (Stroud and Martin, 1968).

A principal limitation to reclamation efforts has been the lack of safe, effective, non-persistent, and preferably selective toxicants in appropriate formulations for warm and cold, acid and alkaline, hard and soft, deep and shallow, thermally stratified and unstratified waters. It was less than 20 years ago that formal investigations were initiated to find and perfect control chemicals specific to fish. Prior to that time, we borrowed our chemical tools, mostly from agricultural entomologists, and attempted to use them against fish without adequate regard for the great and peculiar complexities of aquatic environments.

FISH TOXICANTS

Chemicals have been used since prehistoric times to incapacitate and kill fish. Primitive peoples in South America and Southeast Asia applied rotenone-bearing and other plants to fresh and salt waters to collect fish for food (O'Brien, 1967). Early Chinese employed "fishing plants", particularly "tea-seed cake" made from saponin-bearing seeds of Camellia, to control competing and predaceous fish in fish-culture ponds (Tang, 1961). Extracts from walnut hulls have a long bio-medical history, including use to immobilize and capture fish (Westfall, et al., 1961). Today, rotenone, saponins, and walnut extracts are still of interest in fish control.

The 22 chemicals that have had some use as toxicants in food-fish or sport-fish management in the past 30 years are listed in Table 1. Of them, 12 compounds have had sufficient use to deserve discussion here. The order of discussion is chronological rather than alphabetical .

TABLE 1.

Name	Formula	Reference
Ammonia (anhydrous)	NH_3	In text
Antimycin1/	$C_{28}H_{40}N_2O_9$	In text
Aquathol	C_3H_4O	St. Amant et al. 1964
Bayluscide	$C_{15}H_{15}Cl_2O_5N_3$	Manion, 1969
Calcium carbide	CaC_2	Huston, 1956
Calcium hypochlorite	$Ca(ClO)_2 + 2\ H_2O$	Jackson, 1962
Copper sulfate	$CuSO_4$	In text
DDVP (Vapona)	$C_4H_7Cl_2O_4P$	Srivastava and Konar, 1966
Dibrom-malathion	$C_4H_7O_4PBr_2Cl_2 - C_{10}H_{19}O_6PS_2$	Hoff and Westman, 1965
Endrin	$C_{12}H_3Cl_8O$	In text
Guthion	$C_{10}H_{12}N_3O_3PS_2$	Meyer, 1965
Polychlorpinene	----------	In text
Rotenone1/	$C_{23}H_{22}O_6$	In text
Saponins	Sapogenin glycosides	In text
Sodium cyanide	NaCN	In text
Sodium hydroxide	NaOH	Jackson, 1956
Sodium sulfite	Na_2SO_3	Westman and Hunter, 1956
Squaxin	$C_{21}H_{16}O_2$	In text
TFM1/	$CF_3C_6H_3(NO_2)OH$	In text
Thanite	$C_{13}H_{19}NO_2S$	Lewis, 1968
Thiodan (endosulfan)	$C_9H_6Cl_6O_3S$	In text
Toxaphene	$C_{10}H_{10}Cl_8$	In text

1/ Registered as a fish toxicant in U.S.

Copper sulfate

The use of toxicants in sport fisheries began in Vermont in 1913 when small trout lakes were treated with copper sulfate (Titcomb, 1914. Although copper sulfate kills fish-food organisms and aquatic plants, it is still used to some extent against minnows and other problem fishes. Large crystals of the compound can be dropped into nests of bluegills to kill eggs and fry, but without harm to adults (Allison, 1956). Great care must be exercised when using the toxicant in soft water because the copper ion may be very persistent and cumulative.

Rotenone

Rotenone began to supplant copper sulfate as a fish toxicant in 1934, and it gained rapidly in favor as a result of early trials in Michigan and New Hampshire (Leonard, 1939). At first, powdered derris root containing about 4 percent of rotenone was used in lakes and streams. The difficulties of using the powdered root, however, begged solution, and registered formulations of emulsifiable and synergized rotenone began to appear on the market in the 194O's. By 1949, 34 states and several Canadian provinces were using rotenone routinely in fishery management (Solman, 1950).

Rotenone is by far the most widely and commonly used fish toxicant. Forty states applied almost 700,000 pounds to lakes and streams in 1965 (Stroud and Martin, 1968). Among its advantages are the following: rotenone is well known as a relatively safe pesticide because of long use in agriculture; it is less persistent in water than organochlorine pesticides; and it has low toxicity to birds and mammals. Also, rotenone is available in several properly registered formulations; it is rapidly toxic to many species of fresh water and marine fish; and it can be applied under certain conditions to obtain partial or selective kills of target fish (Kinney, 1968). The intoxification process in fish can be reversed by removing them to fresh water or by immersing them in methylene blue (Bouck and

Ball, 1965; and Oberg, 1967a). Rotenone-laden water can be detoxified by adding potassium permanganate or chlorine (Lawrence, 1956; and Jackson, 1957). Another, but questionable, advantage is the fact that rotenone-killed fish are often collected enthusiastically by the public for table use.

There are, however, some serious disadvantages in rotenone as a fish toxicant. Its toxicity to fish is affected by light, temperature, oxygen concentration, alkalinity, and turbidity, being less effective in very cold or highly alkaline water (Almquist, 1959). Some target species such as carp and bullheads are relatively resistant to it and often require high concentrations and great effort for control. The present formulations repel fish, tending to drive them to any avenue of escape. This repellent effect limits the usefulness of rotenone for partial reclamations or spot treatment of troublesome fish. When applied at the surface of a lake, the formulations also fail to penetrate into depths, thus requiring that they be pumped down into depths greater than 10 to 15 feet.

The fact that rotenone intoxification is reversible is a disadvantage at times. Many fish affected by the chemical during a reclamation sink to the bottom and appear dead, but they may recover completely if currents or seeps expose them to fresh water (Lennon and Parker, 1959).

Rotenone acts as a powerful inhibitor of the respiratory chain in fish, and the site of action is located in the flavoprotein region of the chain. The specialized structure of the gills favors entrance of rotenone into the blood stream via the gills, whereupon the toxicant is transported to vital organs for inhibition of respiration (Oberg, 1967b).

Toxaphene

The insecticide toxaphene began to compete with rotenone as a fish toxicant in 19^8 because of its extreme toxicity and economy (Hemphill, 195*1; and Hooper and Grzenda, 1957). It became the second most-used toxicant in the United States and the principal toxicant.in Canada in the 1950's before its dangers were appreciated. It has also had some limited and careful use in Germany to reclaim small ponds (Anwand, 1968a).

Toxaphene has persisted up to 33 months in Michigan lakes (Hooper and Grzenda, 1957), to 3 years in Canadian lakes (Stroud and Martin, 1968), and to 5 years in Oregon lakes (Terriere, et al., 1966). A study in Wisconsin showed that the toxicant may persist for several years and the components of the compound degrade at different rates (Johnson, et al., 1966). In North Dakota, however, some lakes can be restocked with fish after 7 months (Henegar, 1966), and shallow test lakes in Germany became non-toxic in 3 to 4 months (Anwand, 1968b).

Toxaphene is a hazardous chemical, and no formulations have been registered as fish toxicants. During aerial applications of toxaphene to some Nebraska lakes, 15 to 100 percent of the waterfowl present were killed, and the deaths of some mammals were attributed to the pesticide (McCarraher and Dean, 1959). Residues accumulate in the tissues of fish, and cooking the flesh by boiling or frying has little effect in reducing toxaphene levels.

The insecticidal formulations of toxaphene are not well suited to aquatic use. Because of the known hazards, the Bureau of Sport Fisheries and Wildlife banned further use of toxaphene as a fishery tool in federal operations in 1963, and a number of states soon followed suit (Dykstra and Lennon, 1966).

Endrin

Endrin, an organochlorine insecticide, was tested against fish in 1952 and used as a toxicant in some lakes in 1958. It is reported to be the most powerful fish toxicant known. (Sreenivasan and Natarajan, 1962). In India, for example, endrin has been applied to fish nursery ponds to kill predatory and weed fishes, after which the water is detoxified with large amounts of charcoal (Bhimachar and Tripathi, 1967). Among its disadvantages, endrin is highly toxic to other vertebrates, it persists in water, and it is not registered as a fishery tool.

Polychlorpinene (PCIP)

Russia began research on fish toxicants in 1957 because rotenone and toxaphene are- not available there. Polychlorpinene, an organochlorine compound somewhat resembling toxaphene, was developed in 1959 (Burmakin, 1965). By 1963, 118 lakes in Russia had been treated to remove undesirable fish, and field trials of polychlorpinene were initiated in Germany

(Schaperclaus, 1963).

Polychlorpinene is an economical, stable compound, and- it is used as an insecticide as well as a fish toxicant. It is poisonous to man and other mammals through the skin, gut, or respiratory tract. Some treated lakes in northern Russia remained toxic for about one year. The rate of degradation in water depends on concentration, water temperature, alkalinity, depth, and extent of water mixing. Small, shallow lakes are preferred for treatment, and intensive management for production of food fish usually follows reclamations.

Sodium cyanide was proposed as a fish toxicant in 1958 (Bridges, 1958). It has slowly gained in use since then. Recent investigators state that a 1-ppm concentration in water brings fish to the surface within 30 to 45 minutes, and 50 to 75 percent of fish promptly removed to fresh water recover completely. It is toxic to fish at all temperatures, but works better in warm water; it disappears from water in 4 days at 80°F. and in 10 days at 60°; results are variable in natural waters; and carp and bullheads are more resistant than other species (Miller and Madsen, 1964; and Whitley, 1967).

Investigators also advise that elaborate safety measures be observed during handling and applying sodium cyanide because it is extremely dangerous to man, mammals, and birds. Moreover, the gas emanating from the treated water is toxic to man and mammals, especially when uneven distribution causes high concentrations locally.

Sodium cyanide is not registered as a fish toxicant, and I fail to see any justification for its use in fishery management.

Ammonia (anhydrous)

The use of ammonia in India for killing submerged weeds in food-fish ponds led to recognition of its potential as a fish toxicant in 1960 (Ramachandran, 1960). The ammonia is injected into the water to kill noxious fish and submerged weeds and to fertilize the ponds. The effects remain restricted to treated area. Trials in ponds in Texas disclosed that ammonia yields total kills of fish at high concentrations, selective kills at low concentrations, and profound changes in water chemistry (Klussmann, Champ, and Lock, 1969). Phyto- and zooplankton are decimated and recover slowly. Prawns, tadpoles, and frogs are eliminated. The chemical does not persist long in water, and killed fish are safe to eat.

Anhydrous ammonia is not registered as a fish toxicant, and as presently supplied, it is difficult to use on any but small ponds.

TFM (3-trifluormethyl-4-nitrophenol)

Research begun in the early 1950's by the U.S. Fish and Wildlife Service led to the development of TFM, a selective toxicant for larval sea lampreys (Applegate, et al., 1961). The subsequent, synergistic combination of TFM with Bayluscide gave the Great Lakes Fishery Commission a highly effective toxicant for eliminating the several year classes of lamprey larvae in hundreds of miles of streams tributary to the upper Great Lakes (Howell, et al., 1964. The liquid toxicant is metered with precision into streams to kill lampreys residing in bottom muds with little harm to other aquatic organisms.

TFM is registered as a lampricide. Another important benefit of TFM is the stimulation of further research to find and develop selective toxicants for other pest fish. And, the procedures used in its application — surveys, measurements of stream flows, on-site bioassays, and metered doses — set a standard for stream reclamation in general.

Thiodan (endosulfan) -

Thiodan is a chlorinated hydrocarbon insecticide that is less persistent in water than toxaphene and less toxic to mammals than related insecticides. It was used first as a fish toxicant in Canadian lakes in 1960. It is highly and non-selectively toxic to fish as demonstrated in the well-publicized, accidental fish kill in the Rhine River last summer. Residues of the toxicant accrue in edible tissues of fish, and the future of the compound as a fishery tool remains in question (Schoettger, IN PRESS).

Saponins

The use of saponins for selective control of predaceous fish in shrimp culture ponds in Taiwan was reported in 1961 (Tang, 1961). Saponins are glycosides extracted from plants, and Russian investigators are obtaining the compounds from sugar beets (Bizyaev, Antimov, and Moskalev, 1965). They report that saponins fill a great need for a powerful fish toxicant that is harmless to warm-blooded animals and man and quickly degradeable. The compounds can be used in many situations where polychiorpinene is a safety hazard and too persistent.

Squaxin

Investigators at the University of Idaho began a search in the early 1960's for a selective toxicant for squawfishes (Ptychocheilus spp.), and a chemical called Squaxin was patented in 1968 (MacPhee and Ruelle, 1969). The compound is not toxic to aquatic invertebrates, waterfowl, or mammals at concentrations that kill squawfish. Moreover, within a certain range of water temperatures, Squaxin kills all squawfish without harm to salmon, trout, and other fish. Liquid and powdered formulations are in the process of registration as fish toxicants, and we are certain to hear more of them in coming years.

Antimycin

Antimycin is an antibiotic produced by Streptomyces, and its potential as a fish toxicant was recognized in 1963 (Derse and Strong, 1963). The chemical is relatively specific to fish, i.e., fish killing concentrations are harmless to other aquatic life, waterfowl, and mammals. It is effective in small concentrations against all life stages of fish, egg through adult. It enters fish via the gills and irreversibly blocks cellular respiration at the cytochrome level in the oxidative-phosphorylation pathway. It is odorless and colorless in water, and does not repel fish from treated areas. Thus, it is the first fish toxicant to lend itself well to partial or spot treatments in lakes. It also can be used selectively against target species in certain circumstances (Radonski, 1967; and Burress and Luhning, 1969a and 1969b). Antimycin degrades rapidly in water, usually within a few days or sooner in water with high pH. When necessary, it can be detoxified in water by adding potassium permanganate (Berger et al., 1969; and Gilderhus et al., 1969).

Three registered formulations of antimycin are available to fishery managers. FINTROL-5 consists of antimycin coated on sand grains in such a way as to release the toxicant evenly in the first 5 feet of depth as the sand sinks. FINTROL-15 is similar, but releases the toxicant evenly in the first 15 feet of depth. FINTROL-CONCENTRATE is a liquid for use in streams and very shallow waters. And, experiments are in progress on a cake-type formulation that can be suspended in streams to release a precise amount of antimycin at a consistent rate for a certain prescribed time. The cake formulation, if perfected, would replace the expensive and troublesome, metering devices now used for dispensing liquid toxicant into streams.

Antimycin is versatile and handy, but it is not a panacea. Its sensitivity to pH makes its use in very high pH waters questionable or very expensive. Where bullheads are target fish, their resistance is high enough to make control by antimycin very costly. But, whereas antimycin may appear to be more costly than rotenone, toxaphene, or sodium cyanide in some total-lake treatments, the easy formulations contribute to economy and safety in application, and its non-repellency and irreversible action yield better control of target fish. In many situations, antimycin may be applied only to that stratum of a lake, such as the epilimnion, which contains the target fish. Thus, the expense and time of treating an entire body of water can be avoided.

DISCUSSION

Research in the past 20 years has given fishery managers the relatively sophisticated toxicants, TFM, Squaxin, and Fintrol. But, much more research is needed to provide controls for a wide variety of target fishes living in very complex marine and freshwater environments.

Emphasis must be given to the development of toxicants and control techniques that are highly selective against target fishes. The possibilities of integrated controls in achieving selectivity must be explored, such as toxicants used in conjunction with attractants and repellents, or with electrical seines or barriers.

Getting a fish toxicant into the water, into the depths past thermal barriers, and over wide acreages in brief time continues to be a problem. Lakes and marshes choked or covered with aquatic weeds also pose problems. Thus, the appropriate formulation of toxicants deserves great attention.

It is common practice to treat small bodies of water at the surface, from the shore or by boat. Large waters also are treated at the surface from boats or aircraft. The spraying of a liquid toxicant from boat or aircraft incurs the risk that volatile solvents may evaporate before the insoluble toxicant reaches the water or penetrates the surface film, possibly leaving particulate toxicant on the surface film of the water. Or, a liquid formulation may fall on aquatic vegetation, dry, and remain there. Also, the pumping of liquid toxicants into the depths of lakes is cumbersome, expensive, and often ineffective because of poor or incomplete distribution.

Although liquid toxicants will continue to have a role in fishery management, toxicants formulated in heavier-than-water granules are better suited for distribution by power boat or aircraft, for bouncing off aquatic vegetation into the water, and for penetrating surface film and thermal barriers in water. Some formulations might release their toxicant as the granules sink, as do the FINTROL-5 and FINTROL-15 formulations of antimycin. Other formulations could be designed to release their toxicants in a micro-stratum on the bottom of lakes to control bottom-dwelling, target fishes. Some formulations could go to the bottom and then release their toxicant to the water as the granules dissolve and rise toward the surface. Still other formulations may be developed to release toxicants only on biological substrates.

Much remains to be done in learning the life histories and vulnerabilities of pest fishes, in assessing the needs for control, and in discovering alternatives to direct control. More research is needed also on water quality, particularly as it affects the performance of control chemicals.

The over-riding objective in future fish control must be the ability to control pest fishes where necessary with the greatest possible selectivity and with the least possible contamination of the aquatic environment by toxicants. It is becoming increasingly unacceptable — and rightly so — that an entire lake be treated with a dangerous, persistent toxicant in order to control pest fish that may inhabit only a relatively small portion of the lake.

Fish control still has a long way to go.

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