Effects of fire suppressant foams on a prairie wetland ecosystem – A study of a North Dakota prairie wetland community

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Abstract

During spring 1993, two field exposures were conducted to determine the effects of fire suppressant foams (Silv-Ex and Phos-Chek WD-881) on aquatic life. Exposure #1 was performed in Fish Lake at the Woodworth Field Station, Stutsman County, North Dakota. Exposure #2 was performed in an experimental pond at the National Fisheries Contaminant Research Center in Columbia, Missouri. Twenty-four limnocorrals were designed to enclose approximately 2500 L of water so that chemical dosage could be applied without leakage. Within each limnocorral, fathead minnows and water boatmen (Cenocorixa) were placed in separate environmental chambers to assess effects on single species. Community effects were evaluated by examining aquatic macroinvertebrates that had colonized artificial substrates trays in each limnocorral.

Similar to observations in the laboratory, field studies showed that Silv-Ex was more toxic to aquatic organisms than was Phos-Chek WD-881. Although, in these field studies, no appreciable mortality occurred in fathead minnows exposed to the lowest observed effect concentration (calculated from laboratory data), complete mortality did occur at concentrations approximating the LC50. Analysis of information on macro-invertebrate community responses to these chemicals is in progress.

Résumé

Le printemps 1993, on a mené deux essais d'exposition sur le terrain pour évaluer les effets des mousses carboniques (Silv-Ex et Phos-Chek WD-881) sur la vie aquatique. Le premier essai s'est déroulé au lac Fish, à la Woodworth Field Station, dans le comté de Strutsman, dans le Dakota-Nord. Le deuxième essai a été effectué dans un bassin expérimental, au National Fisheries Contaminant Research Center, à Columbia, dans le Missouri. On a disposé vingt-quatre enceintes limnologiques conçues pour contenir environ 2500 litres d'eau, ce qui permettait d'utiliser le dosage prévu de produits chimiques sans risque de fuite. À l'intérieur de chaque enceinte, on a placé des têtes-de-boule et des corises (Cenocorixa) dans des chambres climatiques distinctes afin d'évaluer les effets du produit sur chaque espèce. On a déterminé les effets sur les populations en étudiant les macro-invertébrés qui ont colonisé les substrats artificiels placés dans chaque enceinte limnologique.

À l'instar des observations en laboratoire, les études sur le terrain indiquaient que le produit Silv-Ex était plus toxique pour les organismes aquatiques que le produit Phos-Chek WD-881. Bien que dans le cadre de ces études sur place, on n'ait pas enregistré un toux important de mortalité chez les têtes-de-boule exposées à la concentration minimale à laquelle des effets sont observés (concentration calculée selon les données de laboratoire), tous les spécimens exposés à des concentrations proches de la DL50 sont morts. On analyse actuellement les données recueillies sur la réponse des populations de macro-invertébrés à ces produits chimiques.

Introduction

Fire retardants and suppressants are widely used in the United States to extinguish wildfires occurring in a wide variety of habitats. These chemicals are often used in locations where aquatic habitats contain sensitive biological communities or threatened and endangered species. Little information is available on the effects of these chemicals on aquatic species. To minimize the probability of producing significant effects on aquatic species, resource managers need to know the environmental risk associated with chemical application. During 1992, toxicity of two fire suppressant foams and three retardants were determined in laboratory exposures. Results from this research suggest that foam suppressants are more toxic than liquid retardants to aquatic organisms under laboratory conditions.

In May 1993, field studies were initiated to evaluate the response of the aquatic community associated with prairie wetland habitat to the foam suppressants,

Silv-Ex and Phos-Chek WD-881. In addition, laboratory and field results were compared, this being an essential link in formulating management options. The purpose of this phase of the study was not only to provide information on aquatic community responses to fire-fighting chemicals in a wetland environment, but also to develop field assessment methods that could be used to determine the effects of these chemicals in a more complex ecological system such as the Great Basin area of Nevada, a study planned and implemented during the summer of 1994. An additional exposure to evaluate the effectiveness of sampling methods and to better define the sensitivity of fish to Silv-Ex was conducted in experimental ponds at the Midwest Science Center. Specific objectives for these studies were:

1) To determine the response of the aquatic invertebrate community to two foaming agents, Silv-Ex and Phos-Chek WD-881, in a wetland environment
2) To evaluate the survival of fish and invertebrates after exposure to Silv-Ex and Phos-Chek WD-881, two foam suppressants.

Description of Study Site

The 1993 study was conducted at the Woodworth Station, a research facility of the Northern Prairie Science Center, Jamestown, North Dakota. The Station is located in Township 142N, Range 68W, on the Missouri Couteau physiographic region of central North Dakota. The region is characterized by thick deposits of glacial till with knob-and-kettle topography. The Station was established in 1963 as a field laboratory for the study of effects of land-use practices on wildlife. Records of land-use practices throughout the Station have been maintained since its establishment. Prior to 1960, the study area was sporadically grazed and hayed. The 65-ha field containing the study site has never been plowed. Biologists burned the field in 1969, 1970, 1971, 1972, 1976, 1979, 1981, and 1990; it has not been grazed since 1974. Currently, vegetation in the study area is dominated by *Poa pratensis*, an exotic cool-season grass. Other grass species found during previous studies on the site include *Stipa viridula*, *S. comata*, *Agropyron repens*, *Muhlenbergia cuspidata*, and *Bromus inermis*. *Rosa arkansana*, *Elaeagnus commutata*, and *Symphoricarpos occidentalis* are common woody plants.

This aquatic study was conducted in Fish Lake, a permanent wetland located on the Woodworth Station. In the recorded history of Woodworth Station, including the drought of the 1930's, Fish Lake has never dried completely.

Methods

Two field exposures were performed in 1993 to examine the effects of two fire suppressant foams, Phos-Chek WD-881 and Silv-Ex, on aquatic life. These tests were conducted as 96-h limnocorral exposures in both North Dakota and Missouri during summer 1993. The first field exposure was performed June 5-9 in Fish Lake, a permanent wetland, at the Northern Prairie Science Center's Woodworth Field Station near Jamestown, North Dakota. The second field exposure was performed August 2-6 in an experimental pond (0.4 ha) at the Midwest Science Center in Columbia, Missouri.

Limnocorral Exposures

Portable limnocorrals were used for both field exposures. Octagonal limnocorrals were designed to enclose approximately 2500 L of water so that chemical dosage could be accomplished without leakage into the surrounding open water area. They were constructed from 1.5" schedule 40 polyvinyl chloride (PVC) pipe and fittings with a bottom edging of polyethylene to create a seal during placement into soft sediments. The limnocorrals were 2.5 m wide x 1.0 m high, and were encircled with 10-mil clear polyethylene plastic. The limnocorrals were built with a 4-way PVC center cross to strengthen the frame and divide the limnocorral into 4 quadrants. A 5-cm hole was drilled in the center to aid in positioning each limnocorral onto 1" galvanized conduit pipe. Limnocorrals were consecutively numbered.

For the North Dakota field exposure, 24 locations with depths ranging from 55-60 cm were identified by placing 1" galvanized conduit pipe at each location along a single transect in Fish Lake . This pipe was used for anchoring and positioning the limnocorrals and for attachment of the artificial substrates. The 24 limnocorrals in this field exposure (8 Silv-Ex, 8 Phos-Chek WD-881, 8 control) were positioned to enclose previously colonized artificial substrates 24 hours before chemical addition.

For preparation of the field exposure at the Midwest Science Center, conduit pipe was placed at 9 locations in a 3 x 3 block at 30-55 cm depths in the experimental pond. Nine limnocorrals (3 Silv-Ex at 6 mg/L, 3 Silv-Ex at 24 mg/L, 3 control) were anchored and positioned in the same manner as in the Fish Lake exposure, 24 hours before chemical addition.

Chemicals and Dosage

Based on laboratory tests conducted by the Yankton Field Research Station (Hamilton, 1993 Progress Report) using fire retardant liquids and suppressant foams, we determined that the foams Silv-Ex and Phos-Chek WD-881 were more toxic to aquatic organisms than the liquid retardants tested. For use in field exposures, concentrations representing the lowest observable effect level (LOEL) for these chemicals were calculated based on this laboratory test data for *Daphnia magna*. The LOEL was calculated as 6 mg/L for Silv-Ex, and 4.7 mg/L for Phos-Chek WD-881. These concentrations were used during the Fish Lake exposure.

To further delineate the effects of foams on aquatic communities, we conducted the second field exposure at the Midwest Science Center. Two exposure concentrations of Silv-Ex were used during this field exposure, one representing the LOEL (6 mg/L) and one representing 4 times the LOEL (24 mg/L). The highest concentration also approximated the laboratory-derived LC50 (concentration expected to induce 50% mortality in a population) for daphnids.

Chemicals were pre-weighed in the laboratory using a Mettler PE360 top-loading balance. Chemical doses were added as a liquid to a 23 L polyethylene container of lake water, then mixed and poured slowly into each limnocorral to avoid agitation. Chemical dosage was added to numbered limnocorrals in a randomized fashion in both field exposures.

Water Chemistry

Continuous Water Quality Monitoring – The variables of pH, dissolved oxygen, conductivity, and water temperature were measured at hourly intervals throughout the study period with DataSonde II units (Hydrolab Inc., Austin, Texas), self-contained submersible dataloggers. One unit was placed outside the limnocorrals in Fish Lake, and 6 units were deployed within randomly selected limnocorrals (2 Silv-Ex, 2 Phos-Chek WD-881, 2 control). Hydrolab units were suspended in the limnocorrals at mid-depth using stainless steel cable clamps. During the second field exposure at the Midwest Science Center, units were deployed in the same manner in each of the three treatments and in open water areas.

Dissolved Oxygen – A YSI dissolved oxygen meter was also used to measure dissolved oxygen between 0700-0900 daily in each limnocorral and in the open water (and the MSC experimental pond) throughout the test period during both field exposures.

Nutrients – One liter water samples were also collected from each limnocorral and the open water areas between 0700-0900 daily during both field exposures. Ammonia (APHA 1985) and orthophosphorus were measured daily throughout the test period. EPA method 365.1 (Colorimatic Automated Ascorbic Acid Method) was used for orthophosphorus determination. Nitrate and nitrite were measured once before and once after each 96-h exposure (APHA 1985).

Other Parameters – The pH was also measured daily from 1-L water samples. Chlorides, sulfates, alkalinity, and hardness were measured once before and once after each 96-h field exposure (APHA 1985). Depth-integrated chlorophyll a samples were collected daily throughout both field exposures with a 45.7 cm acrylic tube placed vertically in each limnocorral and plugged on the top with a rubber stopper. The fluorimetric technique with acetone extraction (APHA 1985) was used for chlorophyll a determination in both exposures. Filters used in this procedure were frozen for further laboratory analysis at the Midwest Science Center.

Single Species *In-Situ* Exposures

Cenocorixa – The water boatman *Cenocorixa* sp. (Hemiptera: Corixidae) was collected from Fish Lake in sufficient numbers for use in the first in-situ field exposure. Winged adults were collected on June 5 prior to chemical addition. Exposure chambers were constructed of 15-L polyethylene containers. For each chamber, 10 x 20 cm windows were cut and fit with 1-mm mesh polypropylene netting. One chamber with 10 Cenocorixa sp. was placed in each of the 24 limnocorrals 1 h after chemical addition. Chambers were suspended from each limnocorral frame. Number of organisms remaining alive was recorded daily throughout the 96-h exposure, with the exception of June 7; inclement weather with extremely high winds made access to the exposure chambers impossible on this day.

Fathead Minnows – An in-situ field exposure with 48-h old fathead minnows (*Pimephales promelas*) was also conducted in an experimental pond at the Midwest Science Center to better define the distribution of mortality for Silv-Ex exposure. Logistical constraints had prohibited use of these organisms in the North Dakota study. Environmental exposure chambers to contain the larval fathead minnows were constructed of 16 x 18 cm cylindrical polyethylene containers fit with stainless steel 0.5-mm mesh screening. The chambers were covered and placed on

square polystyrene floats so that the screened portion of each chamber was below the water. Three chambers were placed in each of the 9 limnocorrals, and 3 additional chambers were placed outside the limnocorrals in the test pond. Twenty fathead minnow larvae were placed in each chamber and acclimated to pond water temperature for 2 hours. Chambers were placed inside each limnocorral 1 h after chemical addition. Number remaining alive was recorded daily throughout the 96-h exposure.

Community Effects

Aquatic Macroinvertebrates – The response of the macroinvertebrate community was evaluated in both the North Dakota and the Midwest Science Center studies using artificial substrate trays that were constructed of 1/2" mesh aquaculture netting (Memphis Net & Twine, Memphis, TN) with a base of PVC pipe and fittings. The tray base was designed specifically for placement into soft sediments. A 30-cm circle of knotless nylon netting was positioned underneath the trays to eliminate organism loss during sampling. The trays contained 5 g of pre-weighed, air-dried Cottonwood (*Populus deltoides*) leaves. Substrate trays were deployed with a PVC pole by pushing the base into the sediment, with tray and netting attached. A nylon pull cord attached to each substrate tray was fastened to the center conduit pipe that anchored and positioned the limnocorral. Substrate trays were sampled by pulling the nylon cord vertically, and placing the tray into a white pan. Substrate trays and nylon netting were placed in zip-lock bags and preserved with 90% ethanol.

For the field exposure in North Dakota, a total of 120 substrate trays were deployed during May 10-11 and allowed to colonize with organisms for 4 weeks before the 96 h dose on June 5. Five substrate trays were deployed at each of the 24 limnocorral locations. Single trays were placed in each limnocorral quadrant (Figure 1), and an additional tray was located immediately outside the corral area. The 24 trays outside the limnocorrals were sampled on June 4 before corral placement. One tray from each limnocorral was also randomly sampled on June 5 after limnocorral placement and before chemical addition to determine disturbance effects associated with limnocorral placement. The remaining 3 trays in each limnocorral were sampled at the end of the 96-h exposure.

For the field exposure at the Midwest Science Center, a total of 116 substrate trays were deployed in the experimental pond on June 20-21, and allowed to colonize with organisms for 6 weeks before the 96-h dose on August 2. Twelve substrate trays were deployed at each of the 9 limnocorral locations (3 for each quadrant), and 8 additional trays were deployed at locations around the outside of the exposure area. The 8 external trays were removed on August 1 before limnocorral placement. One tray from each limnocorral quadrant removed on August 2 after limnocorral placement and before chemical addition to determine disturbance effects. One tray from each quadrant was removed 24 h after chemical addition, and again after the end of the 96-h exposure. Substrate trays that were sampled after chemical addition were immediately washed, processed, and sorted with a #40 brass sieve and white pan to separate dead organisms from the sample before preservation. For a period of 10 min., dead organisms were removed and placed in a separate sample bottle, then preserved in 80% ethanol.

Zooplankton – An 18 x 25 cm aquarium net mounted on a PVC handle at a 100° angle was used to sample zooplankton from each limnocorral and the main lake during the North Dakota field exposure. The net was positioned at a 45.7 cm depth and drawn to the surface. Samples were washed into a bottle and preserved with 80% ethanol. One sample was taken from each limnocorral and 3 samples were taken from the main lake on June 5 before chemical addition. An additional sample was taken from each limnocorral 24 h and 96 h after chemical addition.

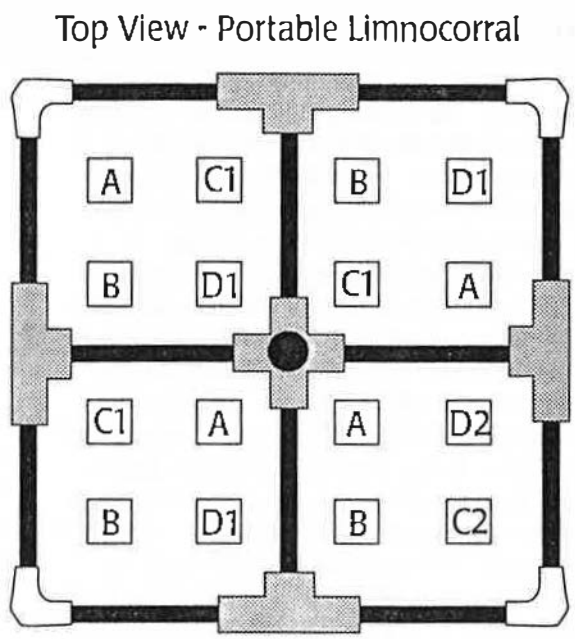

Figure 1. Schematic diagram of limnocorral illustrating placement of artificial substrate trays within each corral. Additional trays were also deployed in open water areas.

Results

Single Species Exposures

Cenocorixa – After 24 h, exposure to Silv-Ex at 6 mg/L resulted in significantly higher mortality of water boatmen (*Cenocorixa* sp.) than in controls ($p = 0.003$) (Figure 2A). The most dramatic decrease in survival (69%) occurred during the first 24 h, but survival continued to decrease throughout the 96-h exposure to Silv-Ex until only 11% of the organisms remained. Contrastingly, the 4.7 mg/L Phos-Chek WD-881 treatment did not cause mortality significantly different from that of controls during the 96-h experiment. However, organisms showed impaired movement that suggested a sublethal response related to chemical exposure.

Fathead Minnows – After 24 hours, the highest Silv-Ex treatment, 24 mg/L, resulted in significantly higher mortality than in the controls ($p = 0.02$) (Figure 2B). As was the case in studies with *Cenocorixa*, survival decreased markedly (64%) during the first 24 hours. After 96 h of exposure, 70 % of the fish had died. The 6 mg/L Silv-Ex treatment, which caused mortality of *Cenocorixa*, did not significantly reduce survival of fathead minnows as compared with controls during the 96-h experiment. In addition, survival of fish in the control limnocorrals was similar to survival of fathead minnows in the open pond, indicating no effects directly attributable to the limnocorral enclosures.

Water Chemistry

Fish Lake is an alkaline, extremely hard, well-buffered aquatic system. The pH ranged from 8.3 to 8.7 with mean hardness and alkalinity of 1345 and 766 mg/L as $CaCO_3$, respectively. In the North Dakota study, water quality conditions among limnocorrals were similar. Hourly data from Hydrolab units indicated that daily patterns in temperature, pH, dissolved oxygen, and conductivity did not differ among limnocorrals or between the corrals and the open water of Fish Lake during the exposure. Water temperatures dropped from 19 to 13°C during the study; this decrease in temperature was caused by a strong cold front on 7 June and resulted in below normal conditions for June in North Dakota. However, this temperature depression did not occur until day 3 of the study and thus, did not coincide with the high mortality observed after a 24-h exposure to Silv-Ex. Dissolved oxygen remained above saturation throughout the exposures and never represented a hazard to aquatic life. No dose-related fluctuations in phosphates, sulfates, chlorides, chlorophyll a, conductivity, or pH occurred during the exposure.

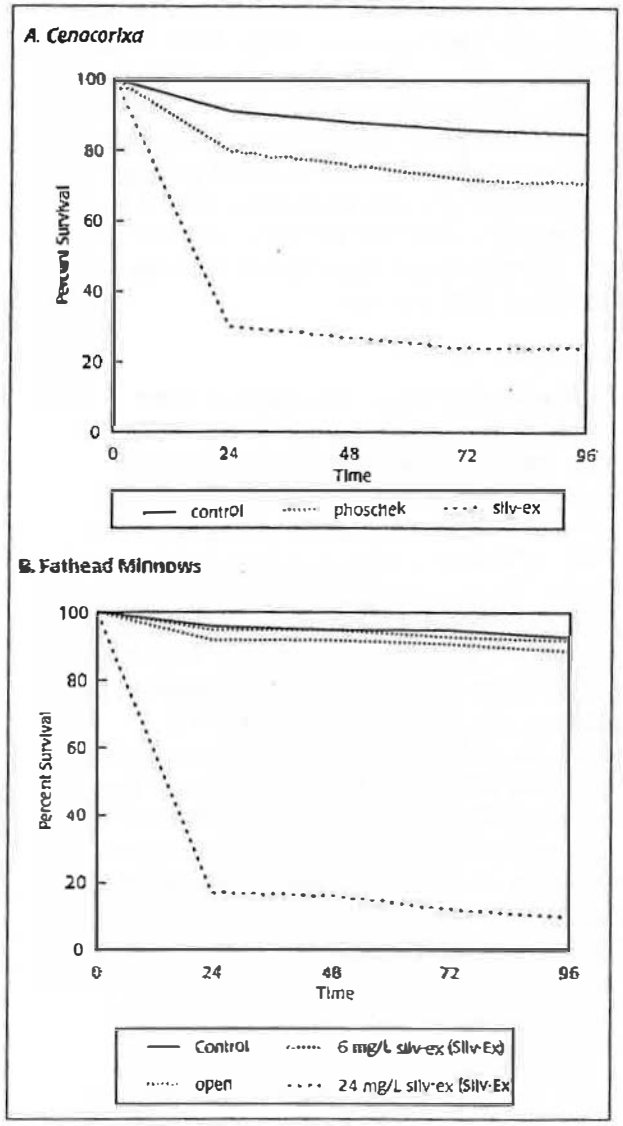

Figure 2A. Survival of *Cenocorixa sp.* (water boatmen) after 96-h exposure to Silv-Ex and Phos-Chek WD-881.

Figure 2B. Survival of fathead minnow larvae after 96-h exposure to treatments of 6 mg/L and 24 mg/L Silv-Ex.

Water quality patterns were also similar among limnocorrals as well as between the corrals and the open water during the study conducted in the Midwest Science Center's experimental pond. This pond is a hard, well-buffered aquatic system with pH ranging from 7.5 to 8.3, a mean hardness of 138 mg/l as $CaCO_3$, and a mean alkalinity of 133 mg/L as $CaCO_3$. Temperature during this exposure ranged from 21 to 26°C. Ammonia was the only water quality variable measured that was affected by treatment. Ammonia in limnocorrals containing the high dose of

Silv-Ex (24 mg/L) increased with time; this trend was not evident in controls or other treatments. However, unionized ammonia in the highest treatment never exceeded concentrations known to be acutely toxic to fish or invertebrates. No dose-related fluctuations in phosphates, sulfates, chlorides, chlorophyll a, conductivity, or pH occurred during the exposure.

Community Effects

Diversity of the aquatic macroinvertebrate community of Fish Lake was extremely low. About 80% of the organisms collected in the artificial substrate trays were chironomids and of these chironomids, two genera dominated the samples. No community-level effects resulting from either Silv-Ex or Phos-Chek WD-881 were evident after the 96-h exposure. Total number of organisms and relative abundance of organisms did not differ among treatments. The Pinkham and Pearson Similarity Index, a similarity index highly sensitive to community disturbance, indicated that for both total number of organisms and relative abundance, treatments did not differ from controls (Figure 3).

Macroinvertebrate samples from the Silv-Ex studies in the Midwest Science Center experimental pond have been sorted and sample identification is about 95% complete.

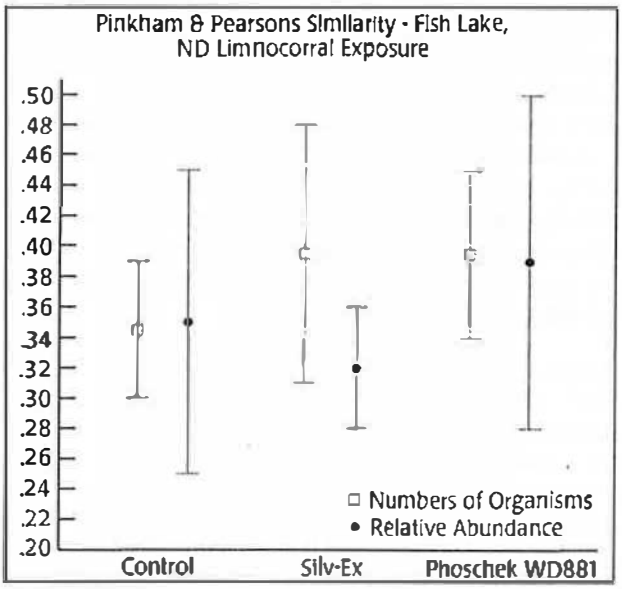

Figure 3. Pinkham and Pearsons Similarity Index calculated for total number of macroinvertebrates and for relative abundance in the North Dakota limnocorral study with Silv-Ex and Phos-Chek WD-881.

Discussion and Management Implications

Under field conditions, the toxicity of Silv-Ex to fathead minnows was similar to that observed in laboratory exposures. For fathead minnows, the Silv-Ex exposure (24 mg/L) that caused significant mortality under field conditions was within the confidence interval of the calculated laboratory LC_{50} for hard water (22 mg/L; 95% CI=17-28) (S. Hamilton 1993 Progress Report). In both instances, the highest mortality occurred during the first 24 hours (Figure 2). In the event of an actual spill or accidental overspray, an organism's response during the first 24 h is an ecologically relevant measure of the severity of a chemical effect. Chemical concentration would be highest at this time because degradation begins immediately; under laboratory conditions, Silv-Ex degrades by 42% in about 20 days (Norecol 1989). However, under natural conditions, that degradation may be accelerated.

In an actual field application example, the acutely toxic concentration of 24 mg/L Silv-Ex identified in our study is equivalent to a spill of 12 L (2.6 gallons) of an 0.5% Silv-Ex (500 mg/L) mixture directly into one 2500 L limnocorral (550 gallons). This equates to a dilution factor of 208 in a natural aquatic system. Therefore, in a pond or wetland environment one would expect mortality of larval fish to occur if a 0.5% Silv-Ex spill was not diluted more than 208 fold. Accordingly, if the Silv-Ex was applied at 1% (10,000 mg/L), the amount of Silv-Ex required to reach the acutely toxic concentration demonstrated in this study would be 6 L in the 2500 L limnocorral; the dilution factor would double to 416. Similar dilution factors are also suggested by Hamilton's data (1993 Progress report) for aquatic invertebrates such as amphipods.

A safety factor is often applied to toxicity data to estimate a "safe" or maximum acceptable toxicant concentration (MATC) for the protection of aquatic organisms. A safety factor of 100 is commonly used (Rand and Petrocelli 1984). Thus, a safety factor of 100 applied to toxicity information for a 1% Silv-Ex mixture from our study would require a 41,600-fold dilution. For example, in a one acre pond with an average depth of 10 feet, use of a safety factor of 100 would estimate that about 78 gallons of 1% Silv-Ex spilled directly into the pond would represent minimal hazard to aquatic organisms. Use of this safety factor provides a conservative value for the protection of larval fish based on results from our study. In the limnocorral exposures, no mortality of fish occurred at a concentration that would be equivalent to a spill of about 1600 gallons of 1% Silv-Ex in a one-acre pond. However, this same concentration resulted in significant mortality of water boatmen (*Cenocorixa*). It

is likely that the mortality of Silv-Ex is related to the surfactants present in the formulation. In rainbow trout, Müller (1980) demonstrated that the toxicity of surfactants was related to their effect on surface tension. As surfactant concentration increased, surface tension decreased and toxicity to trout increased. Because the mobility of water boatmen is dependent on the surface tension of the water, it is likely that their mortality was directly related to the reduction of surface tension caused by Silv-Ex.

Another scenario through which fire-fighting chemicals affect the aquatic environment is by incidental overspray. If this were to occur with Silv-Ex and one were to assume the coverage across the water surface was even, the application of a 0.5% Silv-Ex mixture would result in a 23.6 mg/L chemical concentration in a 2500-L limnocorral. This exposure is similar to the concentration that resulted in significant mortality of larval fathead minnows in both field and laboratory exposures. However, it is highly unlikely that the entire surface of an aquatic system would be covered by a foam such as Silv-Ex. Thus, dilution of the area affected by overspray would occur rapidly. It is unlikely that a concentration as high as that predicted (23.6 mg/L) would actually occur. Nonetheless, organisms such as water boatmen and other invertebrates that utilize the water surface would suffer adverse effects from direct exposure resulting from the chemical application. These organisms along with other important invertebrates such as daphnids and amphipods must be considered as important components contributing to the integrity of an ecosystem. Although aquatic invertebrates are neither economically or recreationally important aquatic resources, they are an integral part of the food chain essential to the support of higher trophic levels such as fish.

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