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Vegetation Re-Establishment on a Hardwood Forest Site Denuded by Brine

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ABSTRACT

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Brine from active oil wells seeped through the soil of a forested site in north-western Pennsylvania and killed all vegetation in its path, leaving the affected area unproductive and unsightly. After the brine source was eliminated, herbaceous plants, shrubs and forest tree seedlings became established and developed rapidly. Establishment began in the first year and by Year 4 the site had developed into a healthy young forest. Results show that Allegheny hardwood forest sites damaged by brine water will rapidly revegetate once the brine discharge is stopped if there is a seed supply and if the area is fenced to exclude deer.

INTRODUCTION

Brine discharge represents a serious environmental problem in north-western Pennsylvania. Brine from oil wells kills forest vegetation and can pollute nearby streams. For these reasons, brine must be disposed of by approved procedures. But spills do occur and the likelihood of spills will increase with increasing oil exploration and production. The effects of brine spills on forest vegetation, the period of time that brine-killed sites may remain toxic and the revegetative patterns on affected areas all need to be studied.

Usually, brine is stored in temporary impoundments where residual amounts of oil are separated. After separation, the brine may be injected into deep wells, sprayed on roads for dust control, treated and discharged to sewage treatment plants, or hauled to approved disposal sites. However, the temporary impoundments are often unlined or improperly sealed allowing leakage or are improperly designed leading to rupture. Thus, brine may seep or flow into adjacent soils and nearby streams or the groundwater below.

At one site on the Allegheny National Forest, brine leaked from an impoundment over a

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period of approximately 3 years and killed the vegetation on about 1 ha. The brine discharge was stopped in 1982 and we observed recolonization of the denuded site by forest vegetation. The objectives of this study were to: (1) measure the damage caused by the brine; (2) document the natural succession of plant species on the brine-killed area over time.

METHODS

The study site was adjacent to an oil storage area, that served 375 wells and was typical of many such areas in north-western Pennsylvania. During the 3-year period prior to 1982, the large quantity of brine generated was diverted into an unlined storage impoundment. This waste water seeped through the impoundment and into the soil of an adjacent Allegheny hardwood stand located downslope.

In May 1982, the oil company replaced the faulty impoundment with two vinyl-lined impoundments. A diversion ditch also was dug between the original leaky impoundment and the study area to prevent any further brine from reaching the damaged site. The killed area was enclosed with a 2.4-m-high fence to exclude deer, because deer have a major effect on vegetation development in north-western Pennsylvania (Marquis and Brenneman, 1981; Bjorkbom and Walters, 1986). At this time, we began to monitor revegetation of the site.

Prior to the brine leakage, the forest stand was fully stocked with second growth, Allegheny hardwoods dominated by hemlock (*Tsuga canadensis* (L.) Carr.) (47%), red maple (*Acer rubrum* L.) (14%), black cherry (*Prunus serotina* Ehrh.) (11%), yellow and sweet birch (*Betula alleghaniensis* Britton and *B. lenta* L.) (10%) and red oak (*Quercus rubra* L.) (10%). These species made up 92% of the total basal area. The stand had an average diameter of 32.5 cm, 42.7 m^2 of basal area ha^{-1}, a relative density of 119% and was 80 years old, except for a few much older residual American beech (*Fagus grandifolia* Ehrh.) and hemlock of the original old-growth forest. The sparse understory consisted of widely scattered, small seedlings of black cherry, serviceberry (*Amelanchier canadensis* (L.) Medic.), flowering dogwood (*Cornus florida* L.) and hawthorn (*Crataesus* spp. L.), and herbaceous species dominated by spring beauty (*Claytonia virginica* L.), trout-lily (*Erythronium americanum* Ker.), wood sorrel (*Oxalis acetosella* L.), sheepsorrel (*Rumex acetosella* L.), violet (*Viola* spp. L.), hayscented fern (*Dicksonia punctilobula* Gray), wood fern (*Dryopteris spinulosa* Muell. Watt.) and Christmas fern (*Polystichum acrostichoides* Schoot.).

We measured and observed the vegetative cover and its development on 15 randomly-located, 1.8-m radius permanent sample plots. This was done annually during autumn for 4 years. On each plot, we determined the number of tree seedlings by species and their average height, and we identified herbaceous vegetation by species and estimated the percentage of ground cover.

Approximately two-thirds of the study area was on a NW-facing slope with a gradient of 25%. The soil was an Ernest silt loam (Aquic Fragiudult, fine-loamy, mixed, mesic) that developed in colluvium. It had 50 cm of permeable soil above an impermeable fragipan. This shallow layer of soil above the fragipan contained all of the roots of the vegetation and was the part of the soil that was continuously saturated with the brine perched above the pan. The other one-third of the site was a somewhat poorly-drained streambottom. The soil here was a Philo sandy loam (Fluvaquentic Dystrochrept, coarse-loamy, mixed, mesic) derived from alluvium. It had a water table at 60 cm and was subject to flooding. Brine saturated this bottomland soil from continuous subsurface flow over the pan from the saturated soil upslope and was then moved off-site in solution with the subsurface flow.

Soil samples were collected from the 0–10 cm depth of the mineral soil near each of the 15 vegetation plots and from 5 areas in the adjacent unaffected stand in autumn 1982. In 1983, only samples from the 10 plots located on the slope were collected. Each sample was a composite of 4 subsamples. Soils were analyzed for pH, P, K, Ca, Mg, Mn, Na and Cl.

Five brine water samples were collected during autumn 1982 to characterize the fluids responsible for killing the vegetation. Samples were analyzed for pH, K, Ca, Mg, Na, Cl, Fe, Mn, Cu, Zn, S, F, Al, Ba, Cd, Cr, Pb, Se, Ni and As. Analyses were completed by the Forest Service Water Quality Laboratory at Winton, Minnesota, U.S.A., according to standard methods (Taras et al., 1971).

RESULTS

The brine seeping through the soil downslope from the impoundment killed all of the vegetation in its path. The swiftness and completeness of the kill attests to the extremely toxic nature of the spilled brine. Ground cover was eliminated immediately, and trees showed visual symptoms of stress during the first growing season after construction of the original impoundment. Hemlock was the first species affected and had yellowish needles occurring acropetally followed by browning, abscission and rapid death of the tree. Visual symptoms of stress in the hardwoods occurred during the same (first) growing season, but after yellowing and browning of hemlock needles had started. All hardwood species present were affected equally, except for large beech which were the last to die. Hardwood stress symptoms were yellow leaves, premature leaf abscission that resulted in sparse crowns and then death. Within three growing seasons after the brine discharge began, all vegetation on the site was dead. The only exceptions were a few scattered clumps of shallow-rooted fern species growing on hummocks and on rotted hemlock logs (Fig. 1A). These slightly elevated microsites probably were not saturated by brine.

The brine contained large amounts of dissolved solids, and had a pH ranging from 6.3 to 6.5. The dominant cations were sodium and calcium and the major anion was chloride. Sodium and chloride were present in extremely high concentrations that exceeded 20 000 and 50 000 mg L^{-1}, respectively. In addition, the brine contained appreciable quantities of heavy metals, principally iron and manganese, as well as a small amount of arsenic. We believe that high concentrations of sodium chloride and calcium chloride salts were responsible for killing the vegetation. The daily discharge of brine to the site was about 22 m^3, a quantity sufficient to keep the area below the storage impoundment saturated year round. Detailed chemical composition of the brine is presented by Auchmoody and Walters (1988).

Chemical analyses of the soil in the brine-killed area and the unaffected adjacent stand in 1982 and 1983 indicate that brine saturation affected the soil by increasing soil pH from 3.8 to 4.4 and increasing concentrations of calcium 20-fold and magnesium 8-fold during both years. Sodium and chloride concentrations were increased significantly during the first year by 40-fold and 25-fold, respectively, but by 1983 had returned to levels similar to those in the undamaged adjacent stand. Phosphorus and manganese in the soil were unaffected by brine saturation. More detailed soil chemical analyses are given in Auchmoody and Walters (1988).

A variety of annual and perennial herbaceous plants returned quickly to the damaged site after elimination of the brine discharge. During the first growing season, 16 herbaceous species became established occupying 11% of the slope and 7% of the bottom. In the years following, species diversity and coverage increased (Fig. 1). After 4 years, the site was completely revegetated and some of the annual pioneer species had already disappeared. The series of annual photographs presented in Fig. 1 illustrate the rapidity of revegetation development observed on this site. Slower vegetation development, as well as some differ-

Fig. 1. General view across the brine kill site from the same point in 1982 (A). 1983 (B). 1984 (C) and 1985 (D). The tallest trees in 1985 were the birches and pin cherry.

ences in species composition, on the streambottom reflects the result of inundation and siltation, rather than differences in residual toxicity between the 2 sites. Therefore, the subsequent discussion will refer to the condition observed on the slope location, except where specifically noted.

Not only has the site become fully revegetated by herbaceous species, but numerous tree seedlings also have become established (Fig. 1). Birch (yellow and sweet), red maple and black cherry have continually been the most numerous commercial species. At the end of the first season, we found 11 000 tree seedlings ha^{-1} representing 13 species (Fig. 2). The number of seedlings nearly doubled in the second season, but then decreased during each of the next 2 years. In 1985, the fourth year after cessation of the brine flow, there was a total of 13 600 seedlings ha^{-1} of which 11 100 were commercial species. In general, tree seedling establishment during the 4-year period was normal, as might be expected in a clearcut (Fig. 3). All species with a nearby seed supply were present with exception of hemlock, which normally does not regenerate under open conditions such as these. Visual symptoms of stress from the brine (yellowish foliage) were not observed for seedlings of any species during any of the 4 years.

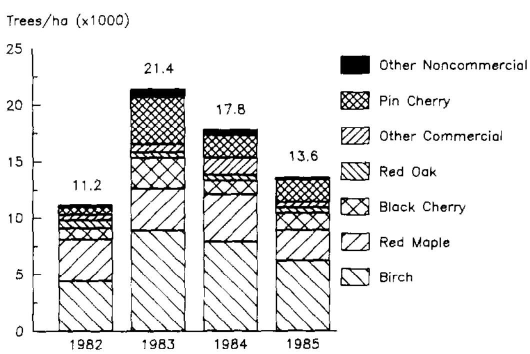

Fig. 2. Species composition during the 4-year period following elimination of the brine source. (Other commercial species are American beech, bigtooth aspen and cucumbertree; other non-commercial species include flowering dogwood, serviceberry and hawthorn.)

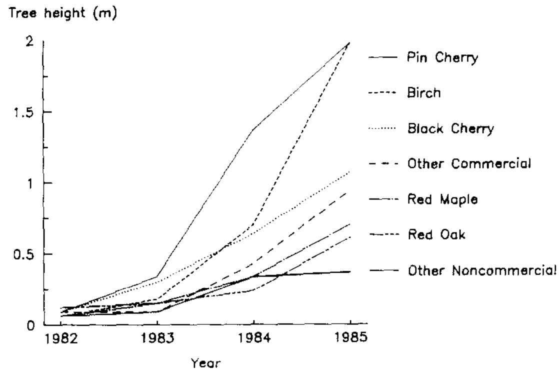

Fig. 3. Average height of tree seedlings invading the brine-affected site during a 4-year period following elimination of the brine source. (Other commercial species and other non-commercial species are the same as in Fig. 2.)

The tallest species were the birches and pin cherry (*Prunus pensylvanica* L.f.), which averaged 1.98 m, and black cherry was next tallest averaging 1.07 m (Fig. 3). Birch height growth in 1984 and 1985 averaged 0.52 and 1.28 m, respectively. In those years, pin cherry grew 1.04 and 0.61 m, and black cherry grew 0.34 and 0.43 m. Although red maple and red oak averaged only 0.70 and 0.61 m in height, respectively, in 1985, they more than doubled their 1984 height by each growing an average of 0.37 m (Fig. 3). These growth rates equal or exceed height growth on similar but undamaged sites in the same general vicinity.

DISCUSSION AND CONCLUSIONS

Death of vegetation caused by brine water may have resulted from the osmotic properties of the brine-saturated soil solution or from elemental toxicity. Most investigators attribute plant damage from brine to the high chloride ion concentration, though sodium–potassium imbalance also may be important. Use of sodium chloride and calcium chloride as de-icing salts is thought to be responsible for much of the damage to vegetation along highways and sidewalks (Dirr, 1976). Sodium, calcium and chloride were found in very high concentrations in our study area.

Allegheny hardwood clearcuts generally revegetate very quickly if protected from deer browsing as we did here by erecting a 2.4-m-high fence (Marquis, 1974; Bjorkbom and Walters, 1986). Protected sites develop dense stands of tree seedlings and stump sprouts, as well as herbaceous plants (Marquis, 1975). Our fenced study site developed similar to a fenced clearcut stand once the brine source was removed. We believe the new vegetation on the site developed mostly from wind-borne seed, seed supplied by the adjacent stand and seeds carried to the site by birds and other small animals after elimination of the brine influence.

Residual effects of the brine did not influence the succession of plant species on this study site. The first plants that grew on the site were the same aggressive pioneer species such as pilewort (*Erechtites hieracifolia* (L.) Ref.), pokeweed (*Phytolacca americana* L.), bramble (*Rubus* spp. L.), grasses (*Gramineae*) and sedges (*Carex* spp. (Ruppinus) L.), that would be expected on any denuded forest site. Pilewort peaked in the second season when it was found on 80% of the sample plots, but has declined thereafter. Bramble seedlings occurred on 60% of the plots the first year, but major development occurred during the second year and has increased each year since then. A dense bramble cover is not viewed as detrimental because of the protection afforded to the site and because most tree species are able to compete with and grow through it (Bjorkbom and Walters, 1986). Although less conspicuous than the other vegetation, tree seedlings germinated abundantly the first year forming a significant portion of the vegetation on the site, and have maintained prominence in the new vegetation since then.

After 4 years, birch, red maple, black cherry and pin cherry dominated the new stand. Hemlock, which made up 47% of the original forest, is absent from the new stand. The numerous black cherry in the 1- to 1.5-m height range are at a stage when they will develop rapidly in height (Auchmoody, 1982). The pin cherry, which is short-lived, will eventually drop out of the stand and provide growing space for development of commercial species. Red oak seedlings are vigorous and abundant, and probably will form a significant component of the emerging stand. Although white ash (*Fraxinus americana* L.) did not occur on any of our regeneration sample plots, this species is present in the area and also will be part of the new forest.

Observations within the brine-killed area suggest that soil nitrogen is abundant, at least more so than on adjacent sites that have been clearcut and not influenced by brine. Though soils tests for nitrogen were not conducted, observations of leaf color and size, as well as rapid terminal growth, indicate good nitrogen availability. This may have occurred from the increase in soil pH brought about by the brine solution.

Patterns of regeneration were similar on the streambottom portions of the site. As on the slope, the brine killed all the vegetation in the streambottom, and revegetation commenced immediately after elimination of the brine discharge. But, revegetation of the bottom area was inhibited by flooding and siltation caused by heavy spring storms in 1982. Therefore, revegetation lagged behind that on the slope by about a year. Grasses and sedges occupied a greater percentage of the bottom and pokeweed and bramble less. Black cherry and pin cherry were not found there, but species that tolerate wet sites, such as birch, white ash and quaking aspen (*Populus tremuloides* Michx.), were found in abundance. Although the forest on the bottom has not regenerated to the same extent or to the same species as on the slope, a suitable forest is developing there that appears unaffected by the brine.

Rapid recolonization of the site by a variety of herbaceous plants and tree seedlings soon after elimination of the brine source is evidence that residual phytotoxicity of the brine is extremely short-lived. We attribute the lack of residual effects to rapid removal of Cl and

Na from the surface soil by leaching. In May and June 1982, the 2 months after the brine source was eliminated, more than 35 cm of precipitation fell (U.S. Dep. Comm., 1982). This was 63% more than average for the period, which provided ample moisture for leaching of the site. Reclamation of salt-polluted soils has sometimes been accomplished by irrigating with fresh water and providing drainage to carry away the leachate (Hettinger, 1982; Tomar and Gupta, 1985). Both of these conditions occurred naturally on our study area.

The first and most important finding from this study is that oil-well waste water is toxic and will kill forest vegetation. Thus, indiscriminate discharge and accidental spilling of brine must be avoided. Also, leak-proof brine impoundments must be constructed, and they must not be allowed to overflow. Brine disposal must follow authorized procedures.

Results also indicate that where brine has been spilled forest sites are not permanently damaged and mitigative treatment to return brine-killed sites to productive forest conditions is unnecessary. However, ameliorative procedures may be needed for reclaiming brine-saturated land where brine water contains hydrocarbons (Hettinger, 1982; Bossert and Bartha, 1985).

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