CHAPTER 9
RIPARIAN RESOURCES

9.1 INTRODUCTION

This chapter presents the determination of injury to riparian resources. Riparian resources include floodplain soils and sediments, riparian vegetation, and wildlife habitat. These resources, together with geologic, surface water, and groundwater resources, and the wildlife dependent upon the riparian zone, constitute the riparian ecosystem.

The information presented in this chapter and previous chapters demonstrates that riparian resources of the Coeur d'Alene River basin have been injured by releases of hazardous substances from mining and mineral processing operations. Specifically:

- Sufficient concentrations exist in pathway resources to transport hazardous substances to floodplains of the Coeur d'Alene River basin.

- Concentrations of hazardous substances in exposed floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are significantly greater than concentrations in reference area soils. Concentrations of hazardous substances in lower Coeur d'Alene River basin sediments are also substantially elevated relative to the reference soils.

- Floodplain soils of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River are phytotoxic (i.e., cause toxicity to plants) relative to control soils. Plant growth performance in field-collected assessment soils was measured under controlled laboratory conditions. Plant growth in contaminated soils was reduced relative to control soils, and plant growth was significantly negatively correlated with concentrations of hazardous substances in the soils.

- Concentrations of hazardous substances in floodplain soils of assessment reaches exceed phytotoxic thresholds identified in the literature, and the observed reductions in plant growth are consistent with the phytotoxic effects of zinc and other heavy metals reported in the literature.

- In the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River, extent of vegetation cover, species richness, and vegetation structural complexity are significantly negatively correlated with concentrations of hazardous substances in soils; percent cover of bare ground is significantly positively correlated with concentrations of hazardous substances. In other words, increased concentrations of soil metals were related to increased bare ground and reduced vegetation.

- Phytotoxic concentrations of hazardous substances in floodplain soils have resulted in significant and substantial reductions in riparian vegetative cover and an increase in the amount of bare ground in the riparian zones of Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River.

- The sources and pathways of metals to floodplain soils of Pine and Moon creeks are similar to the sources and pathways of metals to floodplain soils of Canyon and Ninemile creeks and the South Fork Coeur d'Alene River, and the concentrations of hazardous substances are similar to concentrations determined to be phytotoxic on Canyon and Ninemile creeks and the South Fork Coeur d'Alene River. Therefore, injury to riparian resources of Pine and Moon creeks is inferred to have resulted from phytotoxic concentrations of hazardous substances in floodplain soils.

- Soil phytotoxicity and reductions in vegetation cover have resulted in deterioration of ecological functions, including habitat for all biological resources that are dependent on riparian habitats in the basin; growth media for plants and invertebrates; primary and secondary productivity, carbon storage, nitrogen fixing, decomposition, and nutrient cycling; soil organic matter and allocthonous energy (i.e., carbon from decomposing plant matter) to streams; geochemical exchange processes; food and cover (thermal cover, security cover) for fish, migratory birds, and mammals; feeding and resting areas for fish, migratory birds, and mammals; the migration corridor provided by the riparian zone; habitat for macroinvertebrates; soil/bank stabilization and erosion control; and hydrograph moderation.

9.2 RIPARIAN RESOURCES ASSESSED

9.2.1 Definition of Riparian Resources

Riparian resources include the floodplain soils and sediments, riparian vegetation, and the wildlife that inhabits the riparian zone. Together, these resources and the geologic, surface, and groundwater resources that constitute the riverine environment form the riparian ecosystem.

The riparian zone is the transitional area between the aquatic riverine environment and the terrestrial upland environment. Riparian zones are among the most biologically, chemically, and physically diverse, dynamic, and complex terrestrial ecosystems (Naiman et al., 1993; Naiman and Décamps, 1997; Hedin et al., 1998; Lyon and Sagers, 1998). The riparian zone regulates the flow of energy and materials between the terrestrial and aquatic environments, and between upstream and downstream reaches of streams (Naiman et al., 1993; Naiman and Décamps, 1997). Riparian zones support rich assemblages of plant and animal species (Mosconi and Hutto, 1982; Hansen et al., 1990; Décamps, 1993; Naiman et al., 1993; Moseley and Bursik, 1994; Lyon and Sagers, 1998). Natural riparian zones buffer erosive stream energy, store flood waters and reduce peak flows, and sequester and reduce bioavailable concentrations of pollutants (Karr and Schlosser, 1978; Naiman and Décamps, 1997).

Riparian vegetation helps stabilize the streambanks through anchoring by root networks, and it reduces water velocity by increasing surface roughness (Gregory et al., 1991; Naiman and Décamps, 1997). Riparian vegetation intercepts and stores energy from solar radiation, which influences stream temperature and serves as a source of energy (detrital inputs) for adjacent and downstream aquatic biota (Gregory et al., 1991). Riparian soils, soil biota, and vegetation together regulate the supply of nutrients to the aquatic ecosystem. Riparian soil and vegetation communities help maintain surface and shallow groundwater quality through physical filtering of sediment and attached nutrients by vegetation, plant uptake of nutrients or pollutants, and biotically controlled reactions in soils that release excess nutrients, particularly nitrogen, as gases to the atmosphere (Karr and Schlosser, 1978; Lowrance et al., 1984; Peterjohn and Correll, 1984; Daniels and Gilliam, 1996; Hedin et al., 1998).

Riparian zones typically support highly diverse and productive ecological communities (Décamps, 1993; Naiman and Décamps, 1997). Riparian habitat provides critical connectivity between upland and aquatic habitats for plant and animal species (Mosconi and Hutto, 1982; Doyle, 1990; Knopf and Samson 1994; Sanders and Edge, 1998; Skagen et al., 1998). Vegetative overhang provides fish food (detritus) and cover, and shades the water from solar radiation (Naiman and Décamps, 1997). The abundance of water and forage and the compositional and structural diversity of riparian vegetation communities support wildlife species in numbers disproportionate to the area of the riparian zone.

9.2.2 Riparian Resources of the Coeur d'Alene River Basin

Riparian resources of the Coeur d'Alene River basin include floodplain soils and sediments; riparian vegetation; habitat provided by riparian vegetation, soils, and sediments; and wildlife dependent on riparian habitat. In the Coeur d'Alene River basin, injuries were assessed in riparian ecosystems downstream of major mining activity on Canyon Creek, Ninemile Creek, Moon Creek, Pine Creek, the South Fork Coeur d'Alene River, and the mainstem Coeur d'Alene River and lateral lakes area (Figure 9-1).

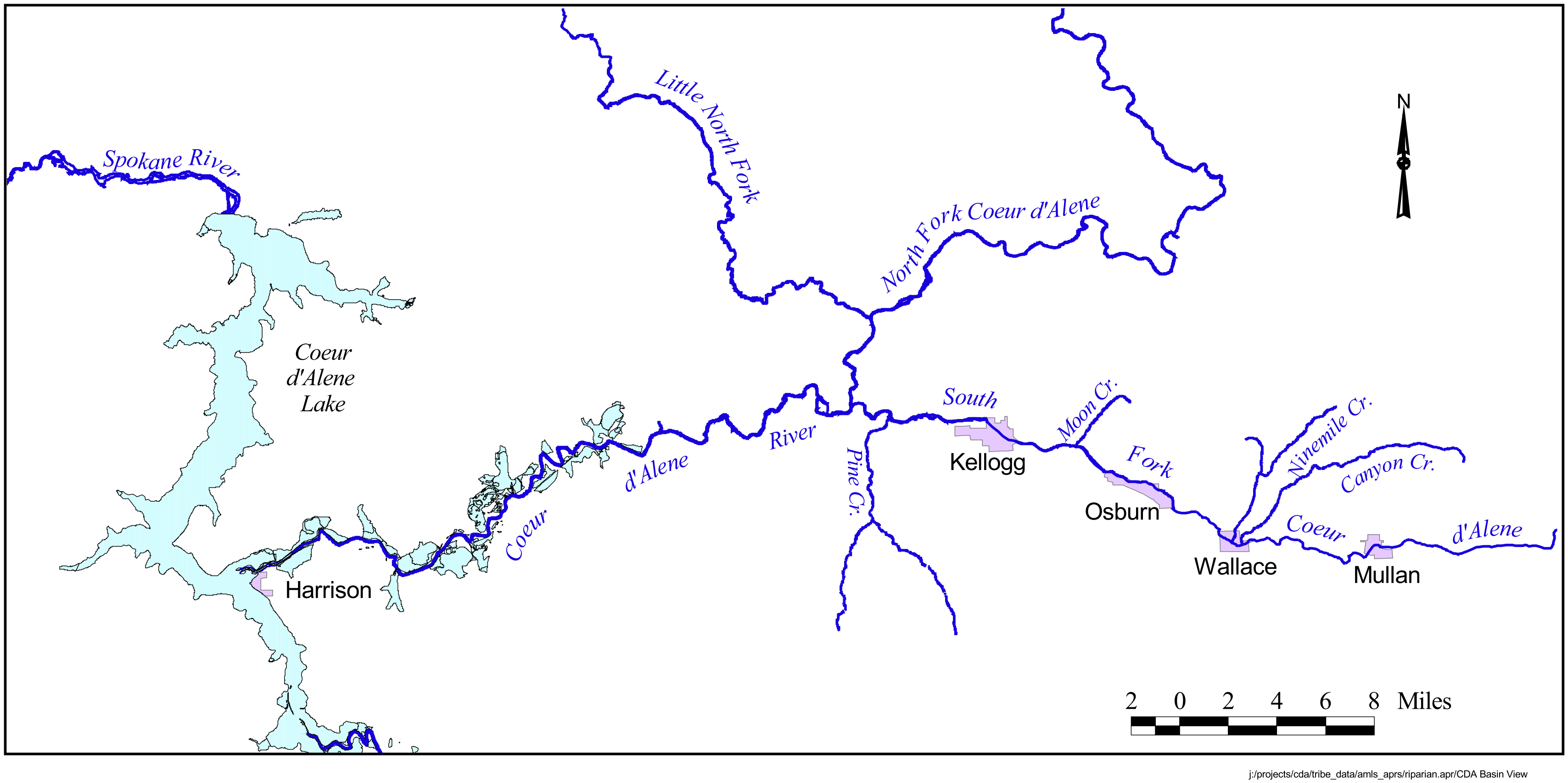

Figure 9-1. Coeur d'Alene River basin.

The South Fork Coeur d'Alene River upstream of Wallace, and Canyon, Ninemile, Moon, and upper Pine creeks flow through steep, narrow canyons with confined channels. These reaches have high gradients, are largely incised, and are channelized in places, either naturally or by roads, railroads, and mining-related disturbances. Downstream of Wallace, the South Fork flows through a broader, U-shaped canyon. Stream and valley gradients downstream of Wallace decrease relative to gradients upstream, and the valley bottom and floodplains widen, although topographic features impose localized channel constrictions. Near Osburn and from Kellogg to Smelterville, the canyon widens further. Within these reaches, the gradient is lower and the floodplain is substantially wider. The riparian zone of the South Fork Coeur d'Alene River downstream of Wallace is modified by industrial, urban, and residential land use. The lower North Fork Coeur d'Alene River, lower Little North Fork of the North Fork Coeur d'Alene River, lower Canyon Creek, and lower Pine Creek also open into U-shaped canyons.

Downstream of the confluence of the South and North Forks, the Coeur d'Alene River is a meandering, low gradient, deep river. The valley opens into a broad alluvial basin, with the floodplain width exceeding one mile in places. The river is bordered by 12 lateral lakes ranging in size from less than 85 acres to over 600 acres (Ridolfi, 1993). Thousands of acres of wetlands are associated with the lateral lakes.

The predominant parent material in the valleys of the South Fork and tributaries of the South Fork is Quaternary alluvium (Derkey et al., 1996). Natural floodplain and low stream terrace soils of the Coeur d'Alene River basin are typically level to nearly level, deep, and very poorly drained to somewhat poorly drained soils formed from mixed alluvium and organic material (U.S. SCS, 1981; 1989). Natural floodplain soils of the Coeur d'Alene River basin, including riparian zones of much of the North Fork Coeur d'Alene River watershed, may support cropland, pasture, woodland, shrubland, or wetlands. However, in the South Fork and mainstem Coeur d'Alene River basins, many of the floodplain and low stream terrace soils are classified as slickens, or tailings that have been mixed with alluvium and deposited along the floodplain (U.S. SCS, 1981; 1989). Slickens contain high concentrations of metals and do not support native or agricultural vegetation (U.S. SCS, 1989). Riparian zones of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, and patches of floodplain along the mainstem Coeur d'Alene River are devoid of vegetation or support sparse communities with low productivity and diversity.

9.3 INJURY DETERMINATION: INJURY DEFINITION

9.3.1 Background: Effects of Metals on Soils, Plants, Riparian Vegetation, and Riparian Habitat

Soils supply the majority of the mineral nutrients necessary for plant growth. Major nutrients derived from soils or soil processes include nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, and iron. Trace elements in soils that are known to be essential for growth and development of organisms include aluminum, boron, cobalt, copper, iron, manganese, molybdenum, silicon, and zinc. Of the most abundant hazardous substances released from mining related operations in the Coeur d'Alene River basin, copper and zinc are essential plant micronutrients, whereas cadmium and lead have no biochemical role in plants (Kabata-Pendias and Pendias, 1992). All micronutrients are toxic in excess concentrations (Van Assche and Clijsters, 1990), but their toxicity in soils depends on the mobility and phytoavailability of metal cations.

The behavior and phytoavailability of hazardous metals in soils are determined in part by their elemental character and speciation, and by specific properties of the soil. The mobility of trace metals in soils depends on soil processes, including sorption, complexation, precipitation, and occlusion; diffusion into clay minerals; and binding or uptake by organic substances (Kabata-Pendias and Pendias, 1992; Brady and Weil, 1996). These processes are strongly controlled by pH and redox potential, and by the amount of clay and organic matter in the soil (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992).

Variability in soil properties, growing conditions, and plant species sensitivity contributes to the specific influence of metal pollutants in soils on plants and on soil services. The same total concentration of metals that is toxic in sandy acid soils may be nontoxic in soils with greater organic carbon content, clay content, carbonates, or iron and manganese hydroxides. As the pH of a soil decreases, cadmium, lead, and zinc concentrations in the soil solution increase, and their mobility and availability to plants increase (Kabata-Pendias and Pendias 1992; Chaney, 1993). Hydrogen ions compete with the metal cations for adsorption on metal binding sites of soils, including clays and humus (Chaney, 1993; Brady and Weil, 1996). Loamy, neutral soils may accumulate high concentrations of metals with few adverse effects, but disruption of chemical balances in metals enriched soils typically results in decreased biological activity and, potentially, saturation of organic and mineral sorption complexes (Tyler et al. 1989; Kabata-Pendias and Pendias, 1992). In soils that contain greater than 20-30% organic matter, large amounts of metals may accumulate with no visible adverse effects to the vegetation (Antonovics et al., 1970).

Plants of different species, and genotypes within species, vary in their ability to absorb trace metals from the same soil environment (Barry and Clark, 1978; MacNicol and Beckett, 1985; Kabata-Pendias and Pendias, 1992). Plants obtain major and trace elements involved in biochemical processes from the soil by both active and passive root uptake. Concentrations of trace elements in plants are often positively correlated with concentrations in soils (Kabata-Pendias and Pendias, 1992). In general, as soil concentrations of trace metals increase, plant tissue concentrations increase. However, above a certain soil or tissue concentration maximum, which varies by species, plant age, and genotype within species, the capacity of a plant to regulate uptake of excess metal contaminants, or of other essential elements in the presence of metal contaminants, is overwhelmed. Shoot and root functions may be inhibited, and uptake of resources from soils may be greatly diminished (Krawczyk et al., 1988). As uptake of resources is reduced, growth is reduced.

At the individual level, phytotoxic responses to heavy metals include stunted shoot growth; stunted, necrotic, chlorotic, or otherwise discolored leaves; and early leaf abscission (Van Assche and Clijsters, 1990; Kabata-Pendias and Pendias, 1992). Roots can exhibit stunted growth, browning or death of the root meristem, and suppressed development of lateral roots (Krawczyk et al., 1988; Kapustka et al., 1995; Rader et al., 1997). Physiological malfunctions include inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, and transpiration (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985; Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990b; Davies, 1990; Kiekens, 1990). Metal toxicity is frequently related to inhibition of enzyme synthesis or activity (Tyler et al., 1989; Van Assche and Clijsters, 1990).

Cadmium inhibits the formation of chlorophyll and interferes with photosynthesis; reduces stomatal conductance and transpiration; inhibits enzyme formation and activity; impedes carbohydrate metabolism; and may also reduce the uptake of other metal ions by roots (Clijsters and Van Assche, 1985; Pahlsson, 1989; Sheoran et al., 1990a,b; Kabata-Pendias and Pendias, 1992). In addition, cadmium has been shown to cause changes in xylem tissue and blockages in xylem tubes which transport water to above-ground tissue (Lamoreaux and Chaney, 1977; Pahlsson, 1989). Symptoms of acute cadmium toxicity include leaf discoloration, wilting, stunted growth, and premature leaf abscission (Vasquez et al., 1989; Alloway, 1990a).

Plants exposed to lead may exhibit decreased photosynthetic and transpiration rates (Davies, 1990). The mechanism of photosynthetic and transpiration reduction is believed to be related to changes in stomatal function (Bazzaz et al., 1974). Lead interferes with the synthesis of chlorophyll and other photosynthetic pigments and inhibits root elongation (Pahlsson, 1989). Uptake of lead has also been shown to inhibit chloroplast activity and to interfere with metabolic processes (Clijsters and Van Assche, 1985; Sheoran et al., 1990a,b). In addition, lead inhibits soil organic matter breakdown, litter decomposition, and nitrogen mineralization in soil, thereby reducing soil productivity (Liang and Tabatabai, 1977; Chang and Broadbent, 1982; Davies, 1990).

Zinc function in plants is related to the metabolism of carbohydrates, proteins, and DNA and RNA synthesis (Kabata-Pendias and Pendias, 1992). In excess concentrations, zinc interferes with chlorophyll synthesis and photosynthesis, blocks water transport in xylem and carbohydrate transport in phloem, and inhibits electron transport (Chaney, 1993; Kiekens, 1990; Pahlsson, 1989; Clijsters and Van Assche, 1985). Zinc may also increase the permeability of root membranes, causing leakage of nutrients and disruption of active transport of ions in and out of the plant (Pahlsson, 1989).

At the community level, phytotoxic responses comprise shifts in plant species composition, or in cases of severe toxicity, reductions in vegetative cover or the elimination of vegetation (LeJeune et al., 1996; Galbraith et al., 1995). Reduced growth, photosynthetic efficiency, or nutrient and water uptake will reduce the ability of metals sensitive plants growing in the wild to compete with more tolerant neighboring plants for limiting resources and to resist natural stressors (Beyer, 1988). Species or individuals that are relatively more sensitive to metals contamination will be eliminated, if not through direct toxic effects, then through reduced viability and competitive ability. Cover of more tolerant species or species able to benefit from the reduced competition for water, nutrients, or light, may increase with the elimination of sensitive species. Since sensitivity and tolerance are governed by numerous processes internal and external to the plant (Kabata-Pendias and Pendias, 1992; Tyler et al., 1989), gradients in tolerance and in community level responses to metals contamination are common. Community level changes in vegetation cover, composition, or structure resulting from phytotoxicity are caused by death and competitive displacement of plants with reduced viability.

Phytotoxic concentrations of cadmium, lead, and zinc in soils have been reported as 3 to 8 mg/kg cadmium, 100 to 400 mg/kg lead, and 70 to 400 mg/kg zinc (Alloway, 1990b). Concentration ranges for phytotoxicity are wide because of differences in metal speciation, soil properties, and plant sensitivity, as discussed above. However, existing data from hard rock mine and metal smelting sites throughout North America and the rest of the world confirm that metals in mine wastes, including metals deposited in smelter emissions and metals in tailings, are commonly toxic to plants. Table 9-1 presents examples of sites where adverse population and community level effects on vegetation, and in agricultural areas, reduced crop productivity, have resulted from mining-related metals toxicity in soils.

Few studies have specifically reported toxic concentrations of metals in floodplain soils contaminated by tailings discharge. Table 9-2 presents data from barren or sparsely vegetated tailings and mixed tailings and alluvium deposits along the Clark Fork River, Montana (LeJeune et al., 1996; Rader et al., 1997) the Conwy River, North Wales (Johnson and Eaton, 1980); and Soda Butte Creek, Montana and Wyoming (Stoughton and Marcus, 2000). The floodplains of the Clark Fork River are contaminated by tailings released from copper mining, and the floodplains of the Conwy River by tailings released from lead-zinc mining. Soda Butte Creek floodplains are contaminated by copper-rich tailings. Although the metals or combination of metals causing the toxicity in each case may differ, the ranges presented for cadmium, lead, and zinc are similar to or lower than ranges of these metals in Coeur d'Alene River basin floodplain soils and sediments (Tables 2-9 through 2-11 and 2-14 through 2-17, Chapter 2, Hazardous Substance Sources). Moreover, these studies provide evidence that metals in floodplain soils are toxic to plants and modify vegetation community characteristics at sites other than the Coeur d'Alene River basin. Devegetation or reduced diversity and productivity of mixed alluvium and tailings in floodplains downstream of mine sites is not unusual.

Table 9-1
Examples of Individual and Community-Level Phytotoxic Effects of Metals Toxicity from Mine Wastes on Vegetation

Mine/Smelter Site	Examples of Phytotoxic Effects on Vegetation
Sudbury Smelter, Ontario (Freedman and Hutchinson, 1979; Lozano and Morrison, 1981)	Devegetation; reduced productivity and diversity; disruption of hardwood nutrition by SO_2, Ni, Cu; colonization by metals tolerant grasses
Palmerton Smelter, PA (Beyer, 1988; Chaney, 1993)	Forest dieback/prevention of regrowth; inhibition of seedling root growth; stunting; changes in species composition and age structure; elimination of grasses
Anaconda Smelter, MT (Galbraith et al., 1995)	Devegetation; reduced species diversity; noxious weed invasion and dominance; reduced habitat quality; inhibition of seedling root growth
Clark Fork River, MT (tailings) (LeJeune et al., 1996; Rader et al., 1997)	Barren or sparsely vegetated floodplain deposits; reduced vegetation structural complexity; reduced habitat quality; reduced seedling root and shoot growth
Tri-State Mining District, OK, MO, KS (tailings) (Pierzynski and Schwab, 1993)	Chlorosis; reduced crop productivity in contaminated floodplains
McLaren Mine, MT/WY (tailings) (Stoughton and Marcus, 2000)	Reduced vegetation biomass, density, diversity in contaminated floodplains
Llanwrst Mining District, Wales (tailings) (Johnson and Eaton, 1980)	Barren or sparsely vegetated floodplains; chlorotic vegetation; reduced diversity; replacement with metals tolerant grasses

In summary, metals released in mine wastes, including tailings and mixed tailings and alluvium, have been shown to cause toxicity to plants at the individual level, as well as devegetation, reduction in vegetation cover and diversity, and reductions in the structural complexity of vegetation at the habitat or community level (Johnson and Eaton, 1980; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000). Loss of riparian vegetation and the functions provided by riparian vegetation degrades the ecological services provided by the riparian ecosystem (LeJeune et al., 1996).

Table 9-2
Ranges of Total Concentrations (mg/kg) of Hazardous Substances in Devegetated or Sparsely Vegetated Riparian Tailings

Riparian Site	pH	Arsenic	Cadmium	Copper	Lead	Zinc
Clark Fork River, MT						
Devegetated tailings+alluvium	3.5-6.2	163-525	1.1-17.8	408-4014	237-885	550-5108
Clark Fork River, MT						
Devegetated tailings+alluvium	4.4-5.4	251-285	3.8-6.2	837-2,840	229-236	765-1,540
Conwy River, North Wales						
>50% bare ground	7.3	—	17-35	—	1,260-2,730	3,760-5,980
< 50% bare ground	7.2	—	12-22	—	860-1,610	2,700-4,200
Continuous cover, chloritic veg.	7.2	—	3.9-10.2	—	210-367	599-812
Soda Butte Creek, MT and WY	6.4	22	—	315	65	170
Reduced vegetation diversity	6.5	—	—	250	—	—
Reduced vegetation density						

— not measured.

Sources: Clark Fork River: LeJeune et al., 1996; Rader et al., 1997. Conwy River: Johnson and Eaton, 1980. Soda Butte Creek: Stoughton and Marcus, 2000.

9.3.2 Data Collected Previously in the Assessment Area

Previous investigations concerning riparian soils, sediments, and vegetation in the Coeur d'Alene River basin include characterizations of the degree and spatial extent of mine waste contamination in various areas of the basin (see Chapter 2, Sources of Hazardous Substances), assessments of plant growth in contaminated floodplain soils and revegetation of floodplains affected by mine wastes (White and Pommerening, 1972; Eisenbarth and Wrigley, 1978; U.S. BOM, 1981, 1983; U.S. BLM 1990, 1991, 1992, 1993; Peyton, 1994), and soil surveys (U.S. SCS, 1981, 1989). In addition, previous field studies and bioassays have demonstrated metals-induced phytotoxicity in soils contaminated by smelter emissions and tailings (e.g., Carter, 1977; Carter and Loewenstein, 1978; Keely, 1979; Krawczyk et al., 1988).

Previous studies characterizing concentrations of metals in floodplain deposits indicated that floodplain deposits of tailings and mixed tailings and alluvium containing elevated concentrations of hazardous substances occur downstream of former mill sites on the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, Pine Creek, and Moon Creek, and in the lower basin (Chapter 2). Summaries of concentrations measured in samples of alluvial materials, including floodplain tailings, mixed tailings and alluvium, and waste rock in the floodplain are presented in Tables 2-9 through 2-11 and 2-14 through 2-17 (Chapter 2). The data presented in Chapters 2 and 3 (Transport and Exposure Pathways) confirm that floodplain materials contain elevated concentrations of hazardous substances, that they are mobile, and that they serve as sources and pathways of hazardous substances to other resources.

Site Characterization

Little data existed previously regarding the structure and composition of riparian vegetation communities of the South Fork or mainstem Coeur d'Alene rivers or tributaries. The U.S. SCS (1981, 1989) mapped areas devoid of vegetation, 30% devegetated, and floodplain, valley floor, and terrace soils containing high concentrations of heavy metals, and noted that high concentrations of heavy metals in alluvial deposits along the South Fork and lower Coeur d'Alene rivers have created poor conditions for plant growth and for most other uses. SAIC and Ecological Planning and Toxicology (1991) reported that surface materials over approximately 450 acres in Smelterville Flats contain concentrations of hazardous substances capable of inducing adverse toxicological effects on plants, soil invertebrates, and small mammals. Metals concentrations were considered to be sufficient in many places to disrupt interactions between and interdependence of soil, plants, and soil fauna and, as a result, to adversely affect soil stability, wildlife habitat, food chain pathways, and nutrient cycling (SAIC and Ecological Planning and Toxicology, 1991). In the 1995 Engineering Evaluation and Cost Analysis for tailings removals in Canyon Creek at Woodland Park, U.S. EPA (1995b) concluded that elimination of vegetative cover in lower Canyon Creek reduced the available wildlife habitat and increased soil erosion.

Plant Growth Studies

Previous greenhouse studies performed in the 1970s and 1980s indicated that Coeur d'Alene soils containing elevated concentrations of hazardous substances cause plant growth inhibition and other adverse effects in controlled laboratory tests (Keely, 1979; Krawczyk et al., 1988). Keely (1979) observed growth reduction (shoot height) of alfalfa, wheat, and peas in soils collected near Osburn and near Kellogg relative to growth of the same species in soils collected from Moscow, Idaho. Krawczyk et al. (1988) observed growth inhibition, reduced survival, and physiological impairment of root development in metals-contaminated soils from the Bunker Hill area relative to control soils.

Krawczyk et al. (1988), using standard laboratory phytotoxicity methods, compared the growth of snap beans (*Phaseolus vulgaris* L. Var Blue Lake 290), tall fescue (*Festuca arundinacea* Schreb), and dandelion (*Taraxacum officinale*) in a mixture of soil collected near the high school in Kellogg and at Smelterville Flats to growth of each species in three control soils. Mean total concentrations of hazardous substances in the test soil mixture were 65 mg/kg cadmium, 483 mg/kg copper, 2,200 mg/kg lead, and 940 mg/kg zinc. Plants were also exposed to a series of test soils with amendments of zeolite (an aluminosilicate mineral with high cation exchange capacity) and lime to determine the effectiveness of these amendments in reducing metals availability. All soils were fertilized initially and throughout the test when plants were watered (Krawczyk et al., 1988). Each species germinated in test and control soils. Bean seedlings (harvested at 69 days) and fescue seedlings (harvested at 100 days) grown in the test soils were stunted relative to fescue and bean seedlings grown in the control soils. Dandelion seedlings in all test soils died within 30 days of germination. Dandelion seedlings in control soils exhibited excellent growth up to the end of the experiment. Amendments had no significant ameliorating effect.

A second experiment was conducted to determine effects on mature dandelions. Mature dandelions grown in a control soil were transplanted to test soil containing a zeolite amendment and to a control soil. At 22 days, plants in the test soil exhibited leaf discoloration and curling. The roots of the plants from the test soil were darker brown and more fibrous than control roots, and histological examination revealed gross morbidity relative to control plants. Impairment of the meristematic zone prevented differentiation of root tissues, and the roots failed to develop vascular tissue and lateral roots. Impairment of root development inhibited water, nutrient, and metal uptake, and the minimal growth observed during the exposure period was attributed to the senescence of the roots (Krawczyk et al., 1988). Root growth impairment as described by Krawczyk et al. (1988) is characteristic of zinc toxicity.

Carter (1977) and Carter and Loewenstein (1978) evaluated relationships between metals concentrations in smelter-contaminated soils and tree seedling survival and growth performance in field plots. Based on plant growth, microbial respiration rates, and concentrations of heavy metals in soils and plant tissues, the authors concluded that concentrations of zinc and other heavy metals were a major cause of seedling mortality. Survival and growth were negatively correlated with zinc concentrations in plant tissues ($r = -0.81$ and $r = -0.57$), and highly positively correlated with microbial respiration rate ($r = 0.84$ and 0.63). Microbial respiration was highly negatively correlated with the heavy metal concentrations in soils ($r = -0.80$). Though the soils tested were not floodplain soils and the source of the contamination was predominantly smelter-related emissions rather than tailings, the concentrations reported were similar to concentrations that have been measured in floodplain soils.

The results of these studies (i.e., plant growth inhibition in Coeur d'Alene soils containing elevated metals concentrations relative to plant growth in control soils, the physiological symptoms of the growth inhibition, and the correlative relationships between metals concentrations and plant growth responses) are consistent with metals as the cause of the observed phytotoxicity.

Field Trials and Revegetation Studies

Between 1972 and 1975, trial plantings of grasses and trees were made in Ninemile Creek on the Star and Day Rock Mill tailings dike, on the ASARCO tailings pond at Osburn, on the Bunker Hill tailings, and at the Shoshone County Airport and Smelterville Flats (White and Pommerening, 1972; U.S. SCS, 1974; Dames & Moore, 1990). Hybrid poplar plantings west of the airport survived, but survival of conifers planted near the Bunker Hill tailings dike was low (U.S. SCS, 1974). Survival of poplar, alder, and willow planted along Ninemile Creek and the South Fork Coeur d'Alene River was variable and greatest for willow. With annual fertilizer addition and irrigation, grass growth on the tailings dikes and ponds was described as "encouraging," but initial grass growth performance on jig tailings at the Shoshone County Airport was poor (U.S. SCS, 1974). Subsequent revegetation trials near the airport and on Smelterville Flats in 1974 and 1975 resulted in improved grass establishment, with greatest success on plots that received 6 inches of organic matter incorporated into the top 8 inches of soil, fertilizer in spring and fall, and irrigation with sewage effluent for the first growing season (Dames & Moore, 1990). By 1987, the most successful revegetation trial plots on Smelterville Flats near the Shoshone County Airport supported an estimated 50 to 60% vegetation cover (Dames & Moore, 1990). The long-term success of these plantings has not been quantified, but recent mapping of floodplain vegetation (Chapter 10, Injury Quantification) indicated that the plantings did not result in self-sustaining vegetation communities.

The University of Idaho College of Forestry, under a grant from the USDA's Surface Environment and Mining (SEAM) program, conducted revegetation research along Ninemile Creek and in the South Fork Coeur d'Alene floodplain between Osburn and Big Creek. Native shrub species, conifer seedlings, and deciduous tree seedlings grown in containers were planted in 1975 and 1977. Survival of native shrubs over three growing seasons was 5% along Ninemile Creek and 38% along the South Fork; growth rates in both areas were retarded (Eisenbarth and Wrigley, 1978). Survival of the conifers was better (33% to 80%), but most of the seedlings exhibited signs of stress attributed to nutrient deficiency and/or toxicity (Eisenbarth and Wrigley, 1978). Again, the long-term success of these plantings has not been quantified, but recent vegetation mapping indicated that large areas of the floodplain between Osburn and Big Creek remain barren (Chapter 10).

The University of Idaho College of Forestry SEAM program also established a grass research plot on Smelterville Flats near the airport. Grass established on irrigated plots that were seeded, fertilized, and mulched by hand. Sparse, irregular growth occurred on irrigated plots where seed, fertilizer and mulch were hydroseeded. Soil analysis indicated a pH of 8, low nutrient and organic matter concentrations, 676 mg/kg lead, and 110 mg/kg zinc (Eisenbarth and Wrigley, 1978). No symptoms of metals toxicity were observed. A subsequent greenhouse test with surface materials collected near the grass research plots showed that plants watered with sewage effluent were significantly larger than plants watered with well water (Eisenbarth and Wrigley, 1978).

The U.S. BOM and the Greater Shoshone County Inc. conducted a study between 1979 and 1983 to assess the feasibility of reclaiming floodplains along the South Fork Coeur d'Alene River and simultaneously developing disposal areas for additional tailings (U.S. BOM, 1981). A test tailings embankment was constructed on the south bank of the South Fork Coeur d'Alene River opposite the Terror Gulch confluence. As part of the study, the suitability of floodplain soils and tailings to support vegetation was assessed. No-treatment unseeded and no-treatment seeded sites exhibited good to very poor growth; lime treatment sites supported light growth, and sites covered with top soil and seeded exhibited excellent growth (U.S. BOM, 1983). All descriptions of growth in treatments were qualitative. Survival of snowberry and hawthorne shrubs and conifer trees planted on the dike faces was initially good, but survival of conifer seedlings on the tailings surface was poor. This area was recently mapped as barren (Chapter 10, Injury Quantification).

In 1990, U.S. BLM seeded grasses and forbs and planted shrubs and trees on a tailings-contaminated 21 acre tract on Smelterville Flats in an attempt to reduce fugitive dust emissions (U.S. BLM, 1990, 1991, 1992). Over 3,000 trees and shrubs, including lodgepole pine, hybrid poplar, black locust, and Siberian pea, were planted. The tract was fertilized in 1990, 1991, and 1992, and approximately 20 acres were irrigated during the 1990 and 1991 growing seasons. In 1991, live vegetative cover in irrigated areas averaged 49%, and tree and shrub survival ranged from 29% (black locust) to 75% (Siberian pea) (U.S. BLM, 1991). By 1993, live vegetation cover increased to 64%, but tree and shrub survival was poor. Herbaceous cover was dominated by redtop, orchardgrass, fescue, and Canada bluegrass (U.S. BLM, 1992; 1993). Vegetative cover was lowest in areas where toxic salt crusts formed on the soil surface (U.S. BLM, 1992; 1993).

In an adjacent companion study also initiated in 1990, the U.S. SCS evaluated the growth performance of 15 varieties of grasses plus the BLM seed mix under dryland and irrigated conditions (Burnworth, 1991, 1992). Five fertilizer and mulch treatments were tested. By 1993, survival of the 15 grass varieties seeded in 1990 was poor. Approximately 80 to 90% of the grass present comprised species that invaded from the BLM seed mix plots, including redtop, orchardgrass, Canada bluegrass, and sheep fescue (Peyton, 1994). Plots that had been irrigated supported approximately twice the grass and litter cover compared to plots that had been mulched only. Plots that had been neither irrigated nor mulched had the greatest amount of bare ground. No differences were observed between the various fertilizer treatments (Peyton, 1994).

At the Cataldo Mission Flats, giant reed grass (*Phragmites communis*) was planted and fertilized in 1972 and 1973, and clover and grain were planted in 1974 (White and Pommerening, 1972; U.S. SCS, 1974). Growth of Phragmites was initially slow, and clover and grain establishment was poor (U.S. SCS, 1974). Revegetation studies by the University of Idaho at the Cataldo Mission Flats between 1975 and 1977 included plantings of seven species of container-grown native shrubs and ponderosa pine, plantings of bare root deciduous trees, and establishment of two grass test plots (Eisenbarth and Wrigley, 1978).

Survival of container-grown native shrubs over three growing seasons was low (26.4%). Survival of container-grown ponderosa pines (*Pinus ponderosa*) over three growing seasons was 70%, but growth of the pines was retarded relative to controls. First and second year survival of the bare root trees was high, but growth was slow. The grass plots reportedly failed because the seedlings were buried by surface materials redistributed by winds (Eisenbarth and Wrigley, 1978).

As part of the recent remedial activity in the Woodland Park area of Canyon Creek, the revegetation effort after tailings removal included planting alder and "metals-tolerant" redtop, with phosphorus amendments to bind lead and zinc in adjacent soils (U.S. EPA, 1995a). The existing lack of vegetation was attributed to limiting soil factors, including low organic matter, heavy metals, and lack of horizon structure. The trees planted as part of the remedial effort did not survive.

In summary, existing data indicated that floodplain soils of the Coeur d'Alene River basin downgradient of mining and mineral processing operations contain elevated concentrations of metals (Chapter 2), and that metals concentrations in floodplain deposits exceed concentrations reported in the literature to be phytotoxic (Kabata-Pendias and Pendias, 1992; Alloway, 1990b). Previous phytotoxicity studies showed reduced growth and physiological impairment of plants in soils collected from the South Fork Coeur d'Alene River valley consistent with metals toxicity (Keely, 1979; Krawczyk et al., 1988), and past revegetation attempts have not successfully re-established self sustaining vegetation communities along the South Fork Coeur d'Alene River and several of its tributaries. Limited soil and vegetation mapping indicated barren and substantially devegetated floodplain areas (U.S. SCS, 1989).

The existing data suggested that chemical toxicity in soils continues to inhibit vegetation re-establishment and growth in the floodplains of the upper Coeur d'Alene River basin.

9.3.3 Injuries Evaluated in the Assessment Area

Injuries evaluated in the assessment area included injuries to floodplain soils and riparian vegetation. Relevant definitions of injury to floodplain soils (and sediments) include:

- concentrations in the soil of substances sufficient to cause a phytotoxic response such as retardation of plant growth [43 CFR § 11.62 (e)(10)]
- concentrations of substances sufficient to raise the . . . soil pH to above 8.5 or to reduce it to below 4.0 [43 CFR § 11.62 (e)(2)]
- concentrations of substances sufficient to have caused injury as defined to surface water, groundwater, air or biological resources when exposed to the substances [43 CFR § 11.62 (e)(11)].

The last definition in this instance applies to injury to vegetation exposed to floodplain soils.

An injury to a biological resource such as vegetation has occurred if the release of a hazardous substance is sufficient to cause one or more of the following adverse changes in viability: death, disease, . . . genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)(i)]. Adverse changes in viability of biological resources can be demonstrated using biological responses that meet the following acceptance criteria:

- The biological response is often the result of exposure to hazardous substances [43 CFR § 11.62 (f)(2)(i)].
- Exposure to hazardous substances is known to cause this biological response in free-ranging organisms [43 CFR § 11.62 (f)(2)(ii)].
- Exposure to hazardous substances is known to cause this biological response in controlled experiments [43 CFR § 11.62 (f)(2)(iii)].
- The biological response measurement is practical to perform and produces scientifically valid results [43 CFR § 11.62 (f)(2)(iv)].

The following injuries to riparian vegetation were evaluated: (1) retardation of plant growth in soils containing hazardous substances relative to plant growth in reference soils, in a controlled laboratory environment [43 CFR § 11.62 (e)(10)], and (2) reduction in vegetation cover and simplification of community structure and composition in the assessment area relative to reference areas. Community level changes are caused by death and physical deformation at the level of the individual plant, where deformations include physiological changes resulting in reduced growth, which leads to a loss in competitiveness and viability. Death and physiological deformations are expressed at the community level as elimination of vegetation or as changes in the composition or structure of vegetation communities.

Growth reduction of individual plants, reductions in vegetation cover, and simplification of vegetation community composition and structure are often the result of exposure to hazardous substances and are known to be caused by exposure to elevated concentrations of metals in soils (Chaney, 1993; Pahlsson, 1989; Kabata-Pendias and Pendias 1992; Kapustka et al., 1995). Growth reductions are the manifestation at the whole-plant level of physiological malfunctions such as inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, and transpiration, and enzyme synthesis or activity, induced by elevated concentrations of trace elements (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985; Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990a; Davies, 1990; Kiekens, 1990). Exposure of plants to metals-contaminated soils in controlled laboratory tests is known to cause shoot and root growth reduction and reduced plant survival (Tyler et al., 1989;

Kapustka et al., 1995). Measurements of reduced growth and survival in laboratory tests and measurements of reduced vegetation cover and changes in community composition and structure in the field are practical to perform and produce scientifically valid results (U.S. DOI, 1987; ASTM, 1994; Kapustka, 1997). These responses meet the four acceptance criteria at 43 CFR § 11.62 (f)(2) and therefore are injuries.

9.4 INJURY ASSESSMENT: TESTING AND SAMPLING APPROACHES

Following a review of studies conducted previously in the assessment area (Section 9.3.2) and a review of published information on effects of metals on soils, plants, and vegetation communities (Section 9.3.1), the Trustees identified the need to collect supplemental data to determine whether floodplain soils and riparian vegetation of the Coeur d'Alene River basin are injured by exposure to hazardous substances and, if so, to quantify the injury.

Existing data indicated that floodplain soils of the Coeur d'Alene River basin downgradient of mining and ore processing operations contain elevated concentrations of metals (Chapter 2), and that metals concentrations in floodplain deposits exceed concentrations reported in the literature to be phytotoxic (Kabata-Pendias and Pendias, 1992). Previous greenhouse studies showed reduced growth of plants in soils collected from the South Fork Coeur d'Alene River valley (Keely, 1979; Krawczyk et al., 1988), and past revegetation attempts had not successfully re-established self-sustaining vegetation communities along the South Fork Coeur d'Alene River and several of its tributaries (e.g., U.S. BLM 1990, 1991, 1992, 1993). Limited soil and vegetation mapping indicated barren and substantially devegetated floodplain areas (U.S. SCS, 1989). Aerial photographs taken in 1992 showed large areas of barren floodplain along the South Fork Coeur d'Alene River and several of its tributaries. Existing data were used to identify testing and sampling objectives, and to identify exposed resources, characteristics of the hazardous substances, and potential injuries and pathways [43 CFR 11.64 (a) (2)].

Since floodplain soils and riparian vegetation are ecologically interdependent, injuries to soil and vegetation resources were assessed collectively. The floodplain soil and riparian vegetation injury determination studies included field and laboratory components (Figure 9-2). Field components included collection of surface soil samples and vegetation community data from floodplains of the Coeur d'Alene River basin. Laboratory components of the assessment included studies of early seedling growth performance in field collected soils under controlled laboratory conditions, and chemical analysis of field collected soils.

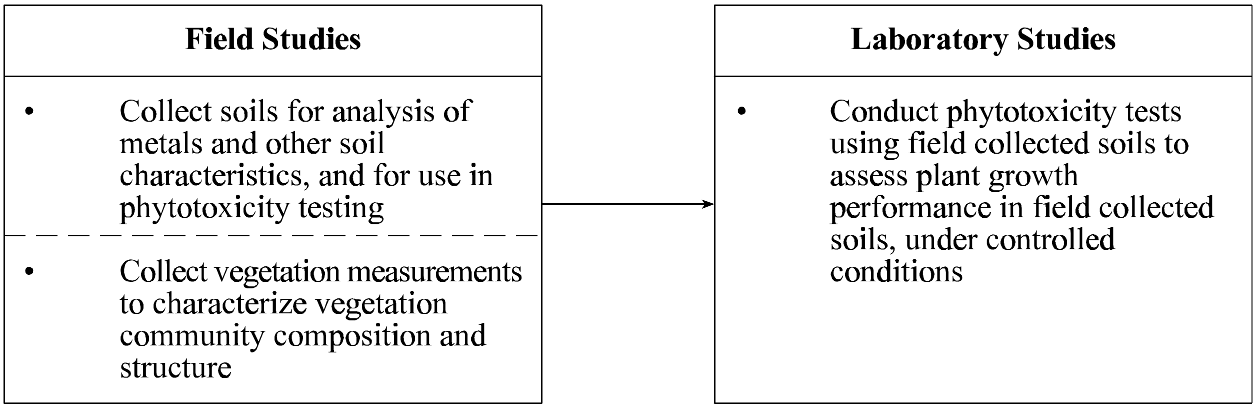

Figure 9-2. Injury assessment studies included field sampling to collect soil and vegetation data from assessment and reference (control) sites, and laboratory studies to evaluate the growth of plants in assessment and reference soils under controlled conditions.

9.4.1 Field Studies

Soil samples and vegetation community data were collected from floodplains downstream of known mining-related disturbances (assessment reaches) and from floodplains upstream of known or major mining related disturbance and on reference streams that have not been mined (presumed unexposed reference reaches). Soil and vegetation data were collected from assessment reaches on Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River between the Canyon Creek confluence and the North Fork Coeur d'Alene River confluence, and from the lower basin and lateral lakes area between approximately the North and South Fork Coeur d'Alene River confluence and the mouth of the mainstem at Coeur d'Alene Lake (Figure 9-3).

Reference Reach Selection

Reference reaches (presumed unexposed control areas) were necessary for comparison of biological and geological characteristics for injury determination [43 CFR 11.62 (f)(3)] and for identification of baseline conditions for injury quantification [43 CFR 11.71 (b)(2-5) and 11.72 (d)]. The DOI NRDA regulations recognize that identification of a reference site is difficult and provide guidelines to assist with selecting similar sites. The reference areas were selected using guidance at 43 CFR 11.72. Reference reaches were selected based on similarity to the assessment reaches in terms of major environmental factors that affect plant growth and vegetation community development and lack of exposure to the release of hazardous substances [43 CFR 11.72 (d)(1)].

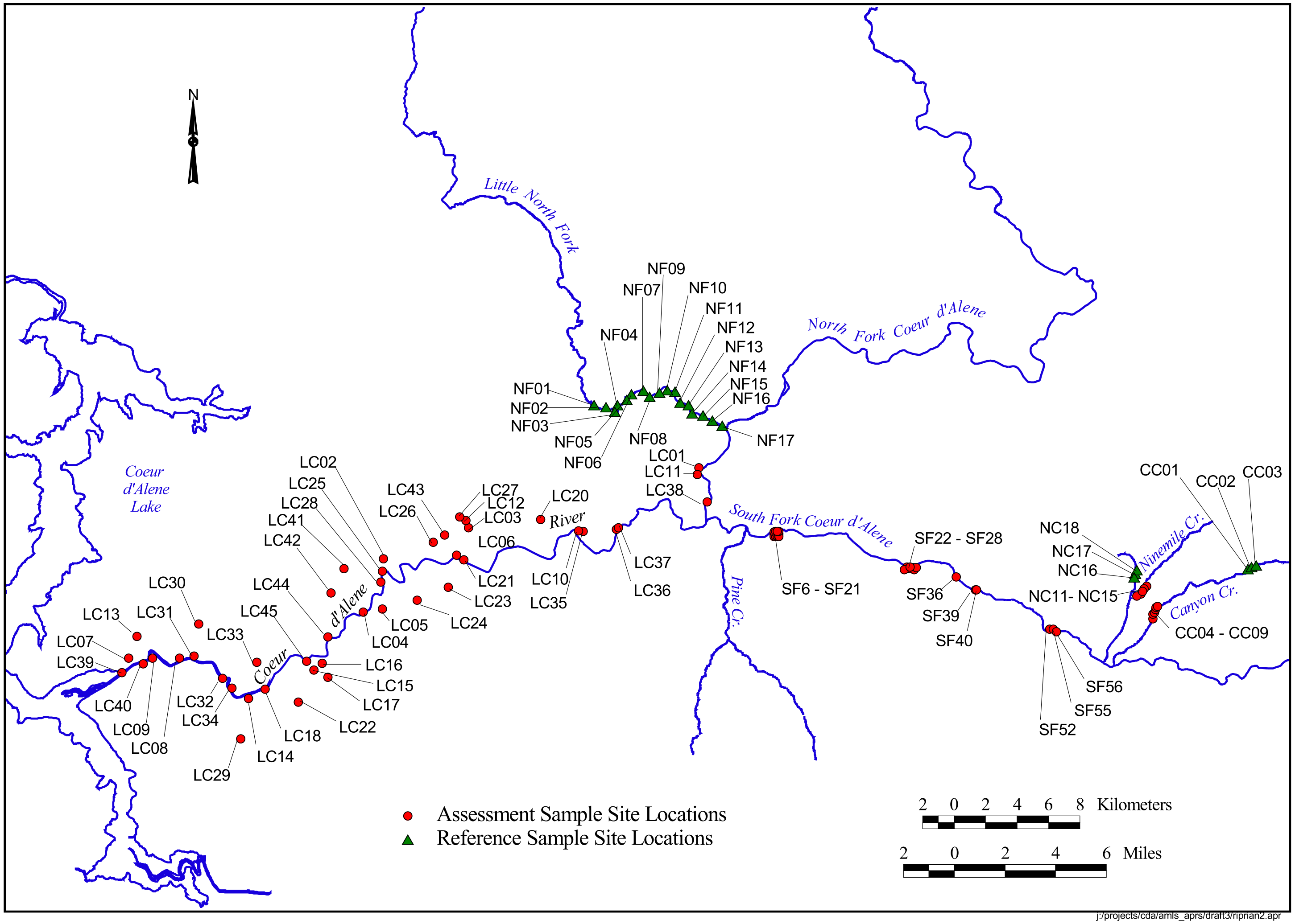

Figure 9-3. Sample site locations for the riparian resources injury assessment. Blue triangles indicate reference sites, and red circles indicate assessment sites.

For floodplain soil/sediment resources, the soil or geologic material in the reference area should be similar to exposed soil or geologic material in the assessment area [43 CFR 11.72 (j)(3)(i)], and at least one reference area upstream of the assessment area shall be included unless local conditions indicate such an area is inapplicable as a reference area [43 CFR 11.72 (d)(2)]. For riparian vegetation resources, references reaches should be physically comparable and comparable to the habitat or ecosystem at the assessment area in terms of distribution, type, species composition, plant cover, vegetative types, quantity, and relationship to other habitats [43 CFR 11.72 (k)(3)(A,B)].

Since vegetation and soil resources are interdependent and were assessed collectively, reference reaches were selected to best address both soil and vegetation reference area considerations identified in the DOI regulations. The reference areas selected are riparian corridors of similar size and orientation, with similar climate, topography, soil parent material, and history. The vegetation types, species composition, plant cover, and structure within each of the reaches is representative of the vegetation types, species composition, plant cover, and structure that should exist in the assessment area. The reference areas have been subjected to anthropogenic alterations including road building, logging, mining-related disturbances, and recreational and residential impacts. Where possible, reference reaches were located upgradient of assessment reaches. Where upstream areas were not appropriate, a reference reach was identified based on proximity to the assessment reach, comparable elevation, and comparable valley orientation.

Soil and vegetation data were collected from reference reaches of Canyon Creek upstream of Burke near Sawmill Gulch, Ninemile Creek upstream of the East Fork Ninemile Creek confluence, and the lower portion of the Little North Fork of the Coeur d’Alene River (Little North Fork) (Figure 9-3). Reference reaches on upstream Canyon Creek and Ninemile Creek upstream of the East Fork Ninemile Creek confluence were selected based on their presumed location upgradient of major mining related influences and the similarity of physical environmental controls on vegetation (e.g., similar climate, similar high gradient, low order streams, and similar expected vegetation types). In addition, like the Canyon and Ninemile creek assessment reaches, both control reaches are bordered by a road. During the riparian resources floodplain soil sampling, it was clear that the predetermined sample sites in the presumptive unexposed reach of Canyon Creek had in fact been exposed to materials resembling mining-related wastes, though to a lesser degree than downstream sites (RCG/Hagler Bailly, 1994). Subsequent chemical analyses of soils confirmed elevated concentrations of hazardous substances in samples collected from two of the Canyon Creek reference sites (Section 9.5.1). Even though the Canyon Creek reference sites do not represent a true control because they have been exposed to mining related releases of hazardous substances, they were retained for analysis and comparison to assessment sites as a conservative estimate of unexposed sites.

The Little North Fork was selected as a reference area for the South Fork Coeur d’Alene River based on similarity of overall climate, the fact that both reaches are mid gradient, mid order streams and both valleys have an approximate east-west orientation, and the similarity of potential vegetation types. The Little North Fork is bordered by a Forest Service road and is an area of high recreational use. The Little North Fork is not bordered by urban development similar to that along the South Fork Coeur d'Alene River, but the vegetation types along the Little North Fork would be expected along the South Fork Coeur d'Alene River at least between urban centers and in broader areas of the floodplain.

An appropriate reference area for the lower Coeur d'Alene River valley and lateral lakes area was not identified. The St. Joe River was considered but rejected based on the heavier agricultural use and the resulting dissimilarity of expected vegetation types. Instead, an internal reference area design was used. Data on lead concentrations in sediments in the lower basin were analyzed to identify sample sites of low to high lead concentrations. Sites containing a range of lead concentrations were sampled to determine whether there are relationships between lead and other hazardous substance concentrations in the soils and sediments and plant growth and vegetation community development.

Upper Basin Sample Site Selection

In the upper basin (i.e., upstream of the South Fork and North Fork Coeur d'Alene River confluence), sampling was confined to public lands in the floodplain. The sampling area was identified using FIRM (1979) flood insurance rate maps to delineate the floodplain, and a digital land coverage map derived from the Idaho Panhandle National Forests secondary base map (USDA FS, 1989) to identify public lands. To select sampling sites from the irregularly shaped plots of public land along the South Fork Coeur d'Alene River, Canyon, and Ninemile creeks, a systematic random sampling in two dimensions (Cochoran, 1977) was used to ensure that every point on public land in these subbasins had equal probability of being sampled. An array of points defined by a 50 m square grid was anchored at a randomly selected point and overlaid on a digital map of public lands within the Coeur d'Alene River basin floodplain using a geographic information system (GIS). Grid points that intersected publicly owned land became the sample sites. Sample sites along the Little North Fork were selected by systematic sampling in one dimension (Cochoran, 1977) along the course of the river. Exact locations perpendicular to the river course (n = 1 per site) were selected by simple random sampling. Sample site geographic coordinates were recorded in the field using a Trimble Navigation Geoexplorer global positioning system. Geographic data were corrected using daily base station data (Spokane, WA). Corrected site locations are accurate to approximately ±5 m.

A preliminary field visit was made to verify sample locations. At that time, locations that were not sampleable were either discarded from the sample set or relocated to the nearest sampleable site. Developed lands, recently remediated lands, and lands currently undergoing remediation were not sampled. In addition, sites that were not sampleable because of differences between the mapped and actual topography were either relocated or eliminated.

Actual sample sites were located in the field using GIS maps and topographic maps. Decisions regarding the exact location of each point were made by the field team leader, based on the prescribed location. Several candidate sites along the South Fork Coeur d'Alene River, Canyon

Creek, and Ninemile Creek were repositioned because of differences between the actual and mapped floodplain morphology. A stratified-random approach was used to reposition sampling sites in the field. To reposition the sampling sites, an interval length was determined by measuring the length of the sampleable area parallel to the creek or river and dividing the length by the number of sample sites that were to be positioned in the sampleable area. A random number between zero and the interval length was obtained using the random number function on a hand-held calculator. The random number determined the starting sample sites in meters from the downstream end of the sampleable area. The interval length was added to position subsequent sites. Sample sites were centered laterally in the floodplain. Railroads and roads were not sampled, and in most cases where they occurred, they bounded the edge of the floodplain.

The procedures described above were intended to prevent bias in the relocation of sample sites. In no case were sample sites selected based on the appearance of a site.

Lower Basin Sample Site Selection

Sample site selection in the lower basin was based on the sampling design and results from a field study by the U.S. Geological Survey (USGS) (Horowitz, 1995). Soil data from approximately 150 sites between Smelterville and the mouth of the mainstem at Harrison were stratified based on measured lead concentration. Lead concentration strata were 0-100 mg/kg lead, 100-500 mg/kg lead, 500-1,000 mg/kg lead, and >1,000 mg/kg lead. Approximately 15 sites per stratum were selected randomly and sampled. This design provided for sampling of soils and vegetation exposed to a wide range of metals concentrations. Sampling included private lands.

For lower Coeur d’Alene sampling, it was not possible at the time of sampling to find previously sampled sites using a GPS, as intended. The field teams instead used topographic maps and written descriptions of sample sites to get as close as possible the previously sampled site. If the location was sampleable, the field team obtained a random distance and direction (using the random number function on a hand-held calculator) to locate the specific sample site. If the location was not sampleable, the field team moved to the nearest similar sampleable location, again using a random direction and distance to locate the specific sampling site. Again, the sample relocation procedures were intended to prevent bias in the relocation of sample points, and no sample sites were selected based on appearance.

In total, 107 sites were sampled, including 63 sites in the upper basin and 44 sites in the lower basin (Figure 9-3). Of the upper basin sites, 40 were located downstream of major mining operations and 23 were located on presumed upstream of mining influenced reaches or on unmined drainages.

Soil and Vegetation Sampling

Soil samples and vegetation data were collected in a systematic sampling array at each site. The soil sample at each site was a composite of five subsamples. Subsamples of equal volume were collected from the 0-15 cm depth at the site center point and at the four vertices of a square surrounding the center point (Figure 9-4). The vertices of the square were 7.75 m from the center point in each of the cardinal directions. The five subsamples were composited in the field to produce a single sample per site for chemical analysis. Duplicate soil samples and decontamination blanks were collected at a frequency of approximately 1 per 25 sites sampled. At a randomly selected 10 reference and 14 exposed sites in the upper basin, and at 12 sites in the lower basin, an additional 10 to 15 L of soil was collected as described above for phytotoxicity tests. Selection of sites for phytotoxicity testing was made before field work began and was not based on the appearance of a site. All sampling was conducted during late August 1994.

Within a 10 m radius of the site center, the following vegetation parameters were visually estimated: most prevalent cover type (the cover type that would shade the greatest proportion of the ground surface were the sun directly overhead), structural habitat layers present (Short, 1984), and approximate areal coverage of each structural layer. Cover type categories included coniferous forest, deciduous forest, coniferous shrubland, deciduous shrubland, grassland and forb pasture, wetlands, bare ground, hay, and dead vegetation. Structural habitat layer categories (Figure 9-5) included terrestrial subsurface layer (topsoil covering at least 5% of the site), understory (vegetation up to 50 cm tall shading at least 5% of the site), shrub midstory (vegetation between 50 cm and 6 m shading at least 5% of the site), tree canopy (trees at least 6 m tall shading at least 5% of the site), and tree bole (trees with trunk diameter of at least 20 cm at breast height) (Short, 1984). Sites could have up to five structural layers.

The species, cover, and height classification of all plants intercepting a north-south 10 m line transect centered at the midpoint of the site were recorded (Kent and Coker, 1992). Height classifications included herbaceous (vegetation up to 50 cm), shrub (vegetation between 50 cm and 6 m), tree (vegetation over 6 m), and litter layer (senescent vegetation on the soil surface) (Short, 1984). Percent cover was calculated as the percentage of the distance of the line transect shaded by a species or height class (Kent and Coker, 1992). Sites with multiple layers of vegetation could have greater than 10 m cover in a given height class. The frequency of each species was the percentage of sites at which the species occurred. Cover and species richness (number of species) were calculated by site for all vegetation, and by herbaceous, shrub, and tree height classes. All plant identification was conducted by trained botanists under the guidance of two botanists with specific expertise in the flora of the Coeur d’Alene River basin.

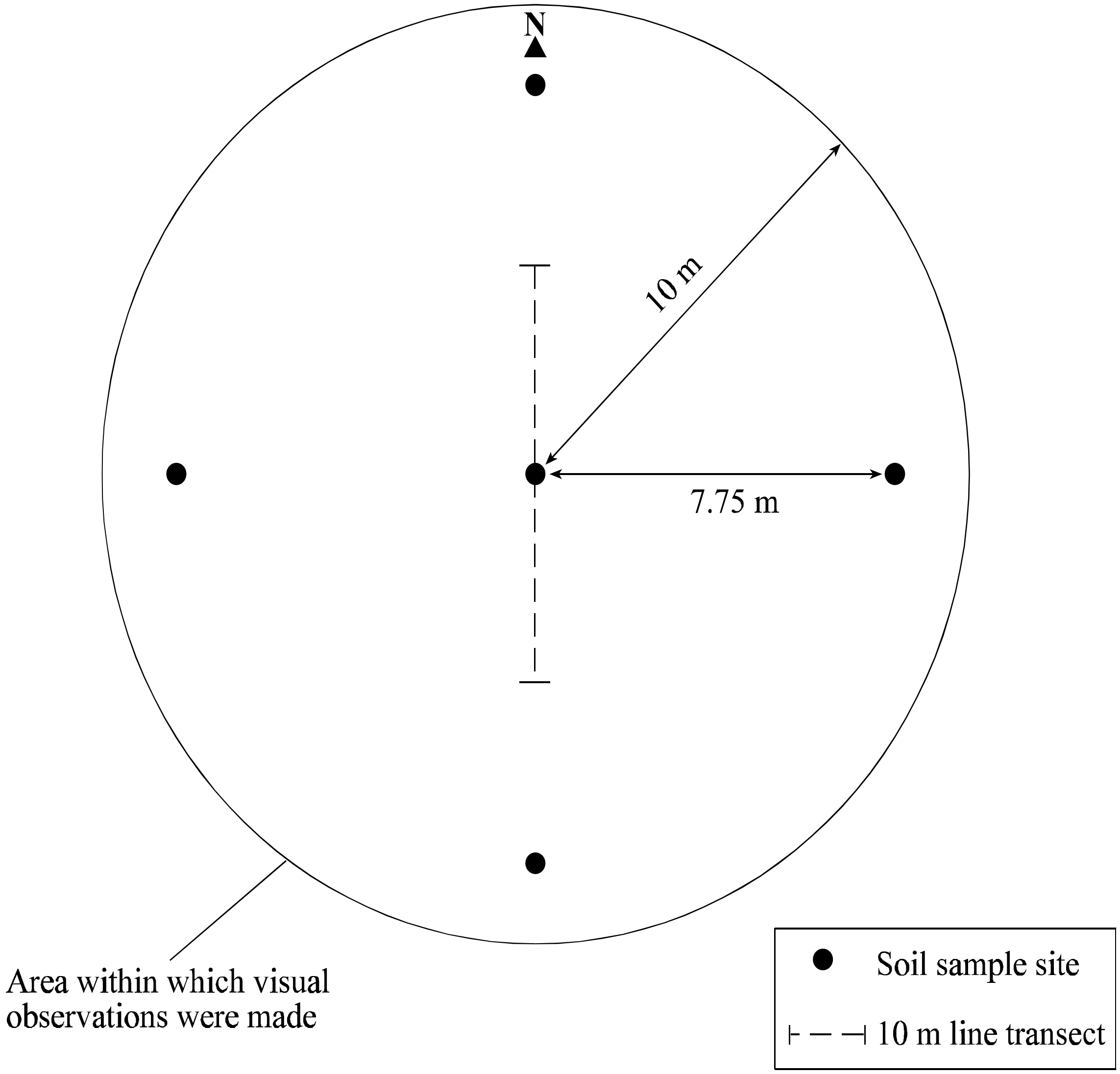

Figure 9-4. Sample site design. Soil subsamples of equal volume were collected from the 0-15 cm depth at five equally spaced points. The composited sample was designed to correspond to vegetation observations made within a 10 m radius of the site center and vegetation measurements made along a line transect.

The vegetation sampling methods are standard methods (Kent and Coker, 1992; Short, 1984) and meet the DOI requirements for quantification of services reduction [43 CFR 11.71 (l)(4, 6)]. They provide numerical vegetation data at the habitat (vegetation community) level that allow comparison between assessment area and reference area data. In addition, they provide data that will be useful in planning for restoration and in measuring restoration success [43 CFR 11.71 (l)(4)(i, ii)].

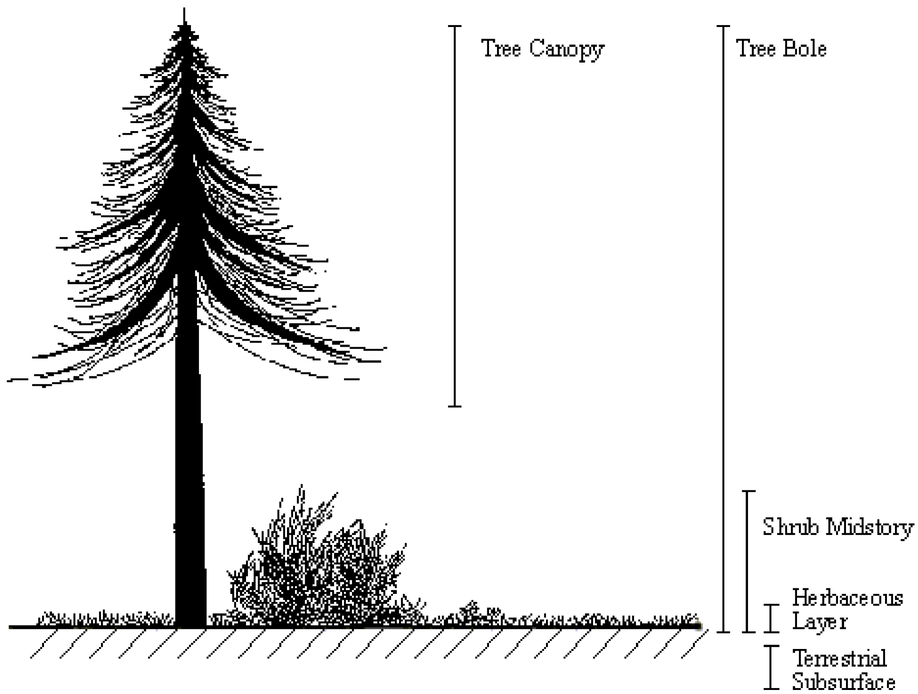

Figure 9-5. Structural habitat layers.

Soil samples were air dried at 40°C and sieved to retain the <2.0 mm fraction. The samples were analyzed using standard methods. Samples for analysis of metals (arsenic, cadmium, copper, iron, lead, manganese, and zinc) were digested with nitric acid (HNO_3) and quantified by EPA Method 3051-M. In addition, samples were analyzed for water soluble nitrate (NO_3) (EPA Method 353.2, Automated Colorimetry); ammonium-bicarbonate diethylenetriaminepentaacetic acid (AB-DTPA) extracted potassium (Page et al., 1982); organic carbon [USDA No. 60 (24)]; saturated paste pH (ASA #9-2, Sec. 12-2.6); and percent sand, silt, and clay (ASTM D 422). All samples were analyzed by inductively coupled plasma (TJA36 Simultaneous ICP) by Method 200.7-M (modified for the Contract Laboratory Program) except for low detects, which were analyzed by graphite furnace atomic absorption spectrometry (EPA Method 206.2 CLP-M) or by ICP mass spectrometry (EPA Method 6020 CLP-M).

9.4.2 Laboratory Studies

Results of the phytotoxicity studies were used to evaluate injury to soils [43 CFR § 11.62 (e)(10)] and to provide supporting evidence of the causal link between hazardous substances in soils, plant growth response, and vegetation community health. The phytotoxicity soil samples were sent to Ecological Planning and Toxicology, Inc. (ep&t), Corvallis, OR for plant growth testing.

The standard early seedling growth protocol (ASTM, 1994) was used to assess phytotoxicity of field collected soils to terrestrial plants.

Test species were selected to represent functional types of native species in the basin. The test species were alfalfa, to represent the nitrogen fixing components of the ecosystem (Leguminosae and Alnus), wheat (Poacea), to represent grasses, and lettuce (Compositae), to represent forb species. Rooted hybrid poplar cuttings were used as a surrogate for native *Populus* spp. and *Salix* spp. Measurement endpoints for alfalfa, lettuce, and wheat included percent germination, root length (mm), shoot length (mm), root mass (g, oven dry), shoot mass (g, oven dry), and total mass (g, oven dry). Measurement endpoints for hybrid poplar included branch length (mm), leaf mass (g, wet weight and oven dry weight of leaves and branches), leaves added (number of leaves), root length (mm), and roots added (number of roots). Phytotoxicity measurement endpoints were consistent with testing and sampling approaches recommended at [43 CFR 11.64 (e)(6)].

The ASTM protocol was adapted for the specific objectives of this assessment. Modifications included use of field collected soils containing the test substances (metals) rather than simulation of field conditions by addition of metals mixtures to artificial soils, and use of field collected reference soils to serve as controls for expected plant growth performance. In addition, positive controls to confirm the susceptibility of test species to chemical toxicity (artificial soil treated with three concentrations of boric acid for hybrid poplars and six concentrations of sodium fluoride for other species) and negative controls to confirm suitable laboratory conditions for plant growth (artificial soil and deionized water for each species) were run simultaneously. The exposure period for alfalfa, wheat, and lettuce was 14 days rather than the 21 day post median emergence date specified in the ASTM guide. The shorter exposure period eliminated the need to add nutrients to the test soils, which would have compromised the relevance of the tests to field conditions. All other aspects of the ASTM guidance were preserved.

Alfalfa, wheat, and lettuce seeds were from the same batch/lot for each of the species. Seeds were not pretreated before testing. Frozen poplar cuttings were supplied by the James River Corporation. Approximately two weeks before test initiation, the poplars were cut to 4 inch lengths, placed in deionized water in a temperature controlled chamber, and allowed to establish a root system. At test initiation, 15 cuttings were randomly selected and removed from the test population. They were measured to establish a pre-test statistical base for maximum length of branches and roots, number of emerging secondary branches, number of visible leaves, number of lateral roots from each primary root, condition and appearance, wet weights of branches and leaves, roots, and primary stem, and dry weights of the branches plus leaves and roots. Information recorded for each test poplar at test initiation included maximum branch and root lengths, and a description of the branches and roots and general condition of the cutting.

Each treatment (soil from a single sample site) consisted of 5 replicate pots of alfalfa, lettuce, and poplar, and 10 replicate pots of wheat. Alfalfa and lettuce replicates contained 20 seeds/pot, wheat replicates contained 10 seeds/pot, and poplar replicates contained 1 cutting per pot. The growth chamber was illuminated on a 16:8 hour light:dark photoperiod, and relative humidity was maintained at >30%. Light period temperature was maintained at approximately 25±2°C. Light intensity during the light period was approximately 100 microeinsteins. Water was added initially and throughout the test as necessary to maintain soils at water-holding capacity.

9.5 INJURY ASSESSMENT STUDIES: RESULTS

This section presents the results of the field and laboratory injury assessment studies. Photographs of sample sites and raw data are included in Appendices A and B to this chapter.

9.5.1 Floodplain Soils

Concentrations of hazardous substances in assessment soils were consistently greater than in reference soils of the upper basin (Figure 9-6) and substantially greater than concentrations reported in the literature to be phytotoxic (Section 9.3.1). Concentrations of arsenic, cadmium, copper, lead, and zinc were significantly greater in South Fork Coeur d'Alene River soils than in Little North Fork soils (Mann-Whitney $p < 0.05$) (Table 9-3). Concentrations of copper, lead, and zinc were significantly greater in Ninemile Creek assessment soils than in reference soils, and concentrations of arsenic, copper, and lead were significantly greater in Canyon Creek assessment soils than in reference soils (Mann-Whitney $p < 0.05$). A pooled comparison of all upper basin assessment soils with upper basin reference soils indicated significantly greater concentrations of arsenic, cadmium, copper, lead, and zinc in assessment soils. Concentrations of cadmium and zinc in Canyon Creek assessment soils were not statistically significantly different from reference soils at the 5% level ($p = 0.09$), but the actual concentrations were substantially different. The degree of difference in concentrations between Canyon Creek assessment and reference soils does indicate that the assessment soils are contaminated relative to the reference soils. However, since the Canyon Creek reference soils had been exposed to mining-related disturbance and contamination, and do contain elevated concentrations of metals relative to sites that were undisturbed by mining, the difference between the two was not statistically significant. Based on the elevated concentrations at the assessment area locations and the observation of mining-related disturbance at two of the three upstream reference locations, the concentrations of cadmium and zinc actually are significantly elevated relative to true nonmining reference conditions.

No significant differences in nitrate-nitrogen, or percent sand, silt, or clay, were detected between Canyon Creek reference and assessment soils, or between Ninemile Creek assessment and reference soils. The range of pH was greater in assessment soils than in reference soils.

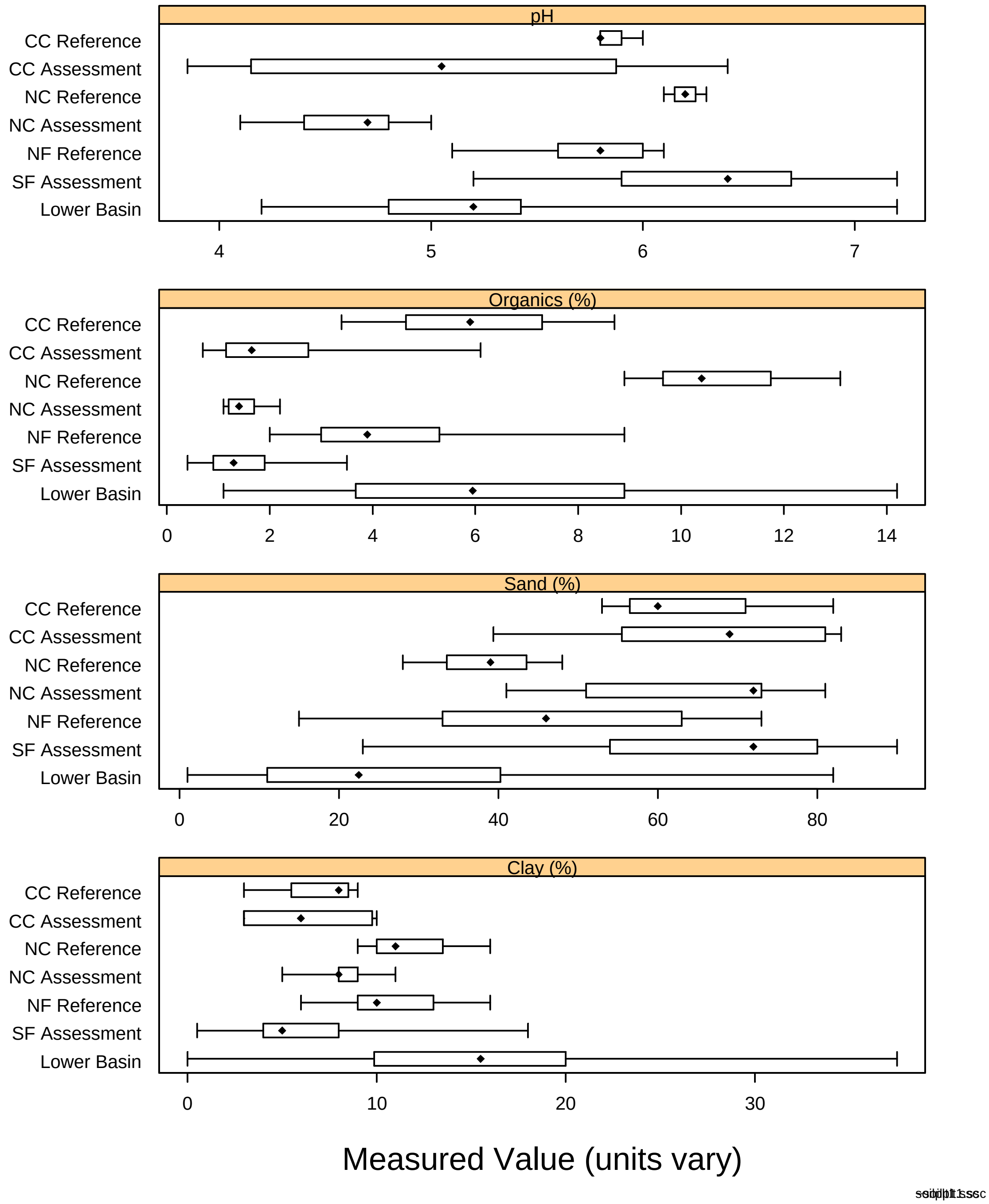

Figure 9-6. Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

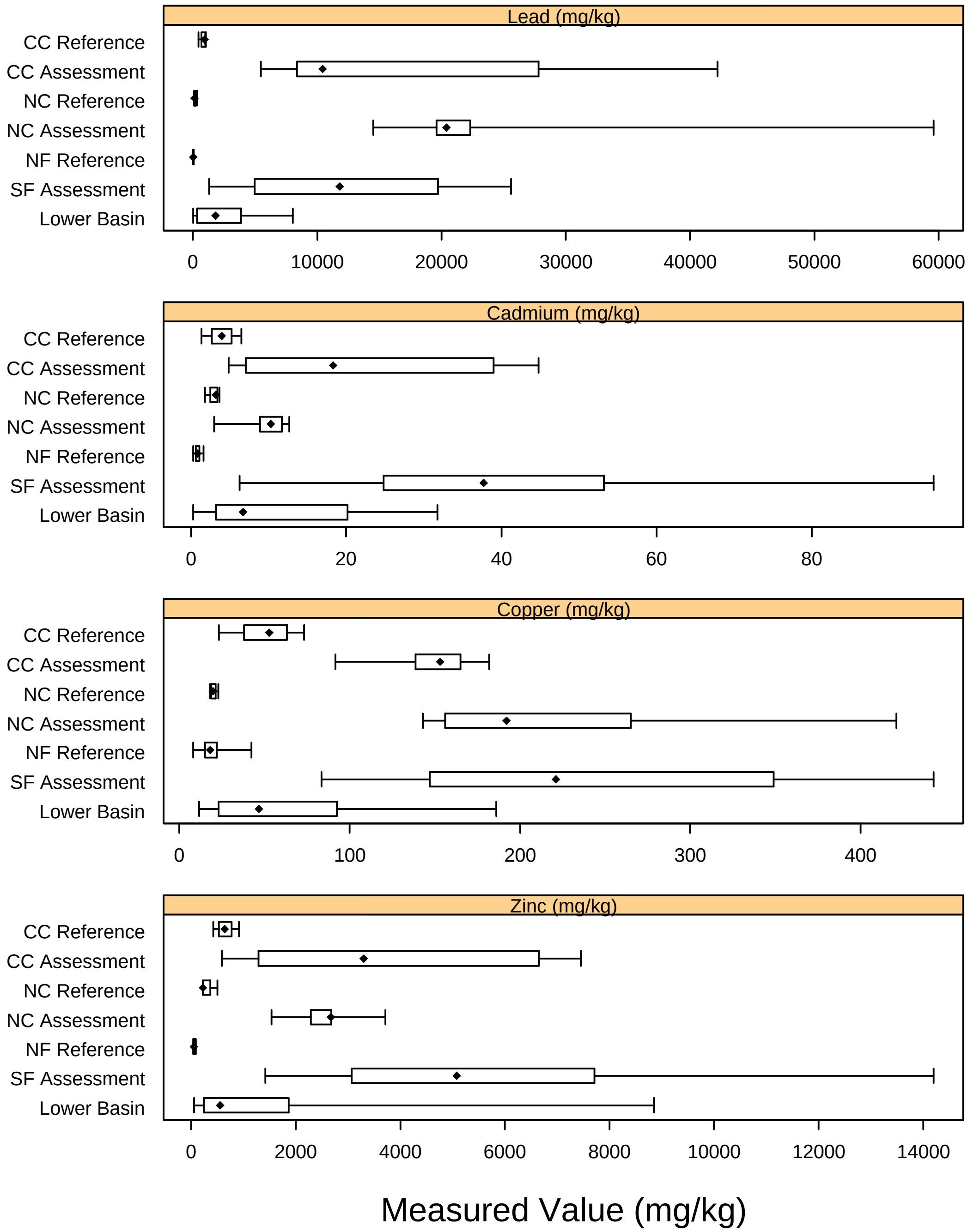

Figure 9-6 (cont.). Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

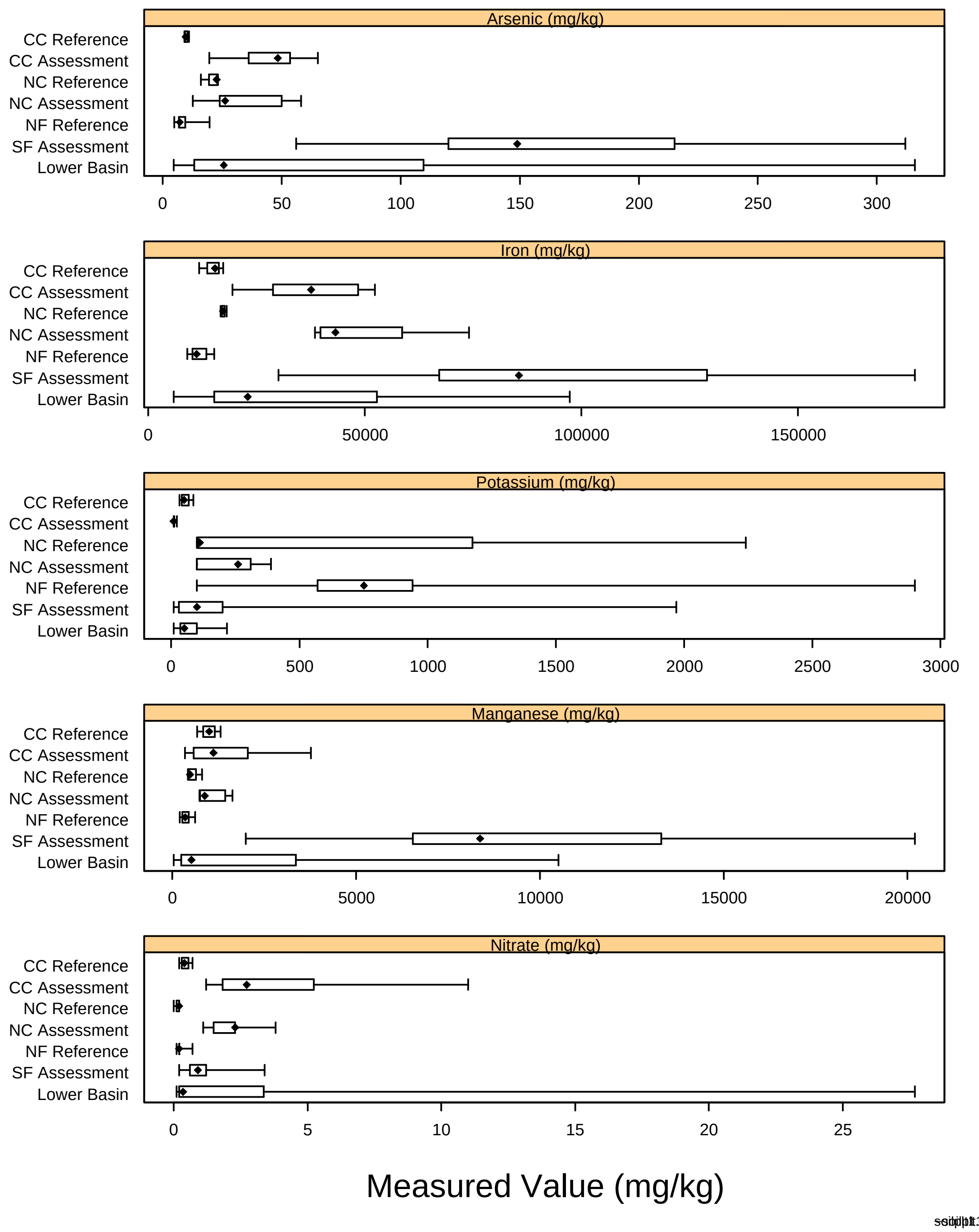

Figure 9-6 (cont.). Distributions of measured soil attributes, summarized by sampling area. Box plots present the maximum, minimum, interquartile range, and median value for each analyte.

Table 9-3
Mean (standard error) Concentrations (mg/kg) of Hazardous Substances in Assessment and Reference Soils

	Arsenic	Cadmium	Copper	Lead	Zinc
Canyon Cr. Reference (n = 3)	9.9 (0.6)	4.0 (1.5)	49.7 (14.5)	802 (182)	661 (143)
Canyon Cr Assessment (n = 6)	44.8 (6.7)[a]	22.6 (7.5)	147 (12.9)[a]	18,300 (6,310)[a]	3,840 (1,260)
Ninemile Cr. Reference (n = 3)	20.6 (2.3)	2.9 (0.6)	20.1 (1.4)	174 (75.3)	318 (94.5)
Ninemile Cr. Assessment (n = 5)	34.2 (8.5)	9.0 (2.0)	235 (51.0)[a]	27,300 (8,180)[a]	2,580 (352)[a]
Little North Fork (n = 17)	8.8 (1.0)	0.8 (01)	19.7 (2.0)	16.8 (1.6)	60.3 (3.7)
South Fork (n = 29)	163 (12.3)[a]	40.5 (3.8)[a]	250 (21.5)[a]	12,400 (1,420)[a]	5,500 (540)[a]
Pooled Upper Basin Reference	10.5 (1.1)	1.5 (0.3)	23.7 (3.0)	140 (59.8)	172 (48.1)
Pooled Upper Basin Assessment	129 (12.6)[a]	33.9 (3.4)[b]	233 (17.6)[b]	15,100 (1,820)[b]	4,890 (46.1)[b]
Lower Coeur d'Alene (n = 43)	71.1 (13.0)	11.3 (1.4)	60.8 (6.9)	2,220 (329)	1,230 (233)

a. $p < 0.05$, Mann-Whitney test.
b. $p < 0.01$, Mann-Whitney test.

Except on the South Fork Coeur d'Alene River, assessment soils were generally more acid than unexposed soils. The pH at all but one site on Canyon Creek (pH = 3.9) exceeded 4. Ninemile Creek assessment soils had significantly lower pH and lower percent organic carbon than Ninemile Creek reference soils. South Fork Coeur d'Alene River soils had significantly greater pH and percent sand than Little North Fork soils, and significantly less silt, clay, and organic carbon ($p < 0.05$; Figure 9-6).

Concentrations of hazardous substances in lower Coeur d'Alene soils were generally lower than those in assessment soils of the upper basin, but concentrations of organic carbon and clay were generally greater (Figure 9-6). Concentration means and ranges by subarea of the lower basin are presented in Table 5-1 (Chapter 5, Sediment Resources).

9.5.2 Plant Growth Tests

Plant growth performance in assessment and reference soils was compared by species and endpoint. For comparison, data from each of the reference areas (Little North Fork, Canyon Creek, and Ninemile Creek) were pooled, and data from the assessment areas (South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek) were pooled. Table 9-4 summarizes the results of phytotoxicity tests in upper basin soils by species and endpoint. Comparisons in which the lower Coeur d'Alene samples were included as assessment samples were also made. However, there was little evidence of a concentration-response relationship in lower Coeur d'Alene soils used in the phytotoxicity tests, so injury assessment, and the following presentation of results, focused on upper basin soils.

Table 9-4
Summary of Growth Responses of Alfalfa, Wheat, Lettuce, and Poplar in Upper Basin Soils

Endpoint	Soil Source	N	Mean	Median	SD	Minimum	Maximum
Alfalfa							
Root Length	Assessment Reference	13 10	28.5 46.1	24.5 43.3	22.7 22.1	2.6 19.1	75.1 85.7
Root Mass	Assessment Reference	13 10	0.015 0.017	0.013 0.014	0.012 0.013	0.001 0.001	0.037 0.037
Shoot Length	Assessment Reference	13 10	32.1 60.8	38.2 56.0	16.7 13.6	7.8 44.7	54.8 82.5
Shoot Mass	Assessment Reference	13 10	0.042 0.072	0.046 0.088	0.026 0.046	0.006 0.004	0.093 0.121
Total Length	Assessment Reference	13 10	60.7 107	61.6 95.3	38.0 31.8	11.9 68.6	130 161
Total Mass	Assessment Reference	13 10	0.058 0.089	0.061 0.105	0.037 0.055	0.007 0.005	0.129 0.145
Lettuce							
Root Length	Assessment Reference	13 10	28.7 41.7	31.0 43.4	22.1 10.3	0.9 23.2	67.6 57.5
Root Mass	Assessment Reference	13 10	0.012 0.022	0.007 0.020	0.014 0.013	0.000 0.001	0.039 0.050
Shoot Length	Assessment Reference	13 10	27.7 53.1	31.9 52.3	15.8 12.3	7.0 33.0	53.0 69.2
Shoot Mass	Assessment Reference	13 10	0.042 0.072	0.034 0.078	0.035 0.031	0.004 0.004	0.110 0.109
Total Length	Assessment Reference	13 10	56.3 94.9	61.6 93.8	37.2 16.7	8.5 56.2	116 114
Total Mass	Assessment Reference	13 10	0.054 0.094	0.041 0.101	0.047 0.039	0.006 0.005	0.146 0.136

Table 9-4 (cont.)
Summary of Growth Responses of Alfalfa, Wheat, Lettuce, and Poplar in Upper Basin Soils

Endpoint	Soil Source	N	Mean	Median	SD	Minimum	Maximum
Wheat							
Root Length	Assessment Reference	14 10	139 207	181 212	101 28	5.3 167	249 239
Root Mass	Assessment Reference	14 10	0.016 0.017	0.017 0.017	0.007 0.003	0.008 0.013	0.026 0.020
Shoot Length	Assessment Reference	14 10	152 239	181 239	50 19	57.4 209	202 275
Shoot Mass	Assessment Reference	14 10	0.020 0.032	0.021 0.032	0.006 0.003	0.010 0.027	0.028 0.039
Total Length	Assessment Reference	14 10	291 446	350 449	149 43	63 389	443 512
Total Mass	Assessment Reference	14 10	0.036 0.049	0.039 0.048	0.012 0.005	0.018 0.043	0.053 0.058
Poplar							
Branch Growth	Assessment Reference	7 5	163 253	199 262	82 26	36.0 223	239 282
Leaf Mass	Assessment Reference	7 5	3.96 5.81	4.80 5.75	2.08 0.60	0.73 4.96	5.69 6.56
Leaves Added	Assessment Reference	7 5	4.26 6.68	4.60 6.00	2.39 2.11	0.80 5.40	6.40 10.40
Root Growth	Assessment Reference	7 5	77.8 151	113 132	68.3 32	-22.6 122	136 193
Roots Added	Assessment Reference	7 5	4.26 6.68	4.60 6.00	2.39 2.11	0.80 5.40	6.40 10.40

Since there is no regulatory or "standard" definition of toxicity for plants, phytotoxicity was defined as a significant difference ($p < 0.05$) from reference. Plant growth was reduced significantly in assessment soils relative to reference soils for all species tested. Shoot length and total length of alfalfa, lettuce, and wheat, and shoot mass and total mass of wheat were significantly ($p < 0.05$) reduced in assessment soils relative to reference soils (Table 9-5). Shoot and root mass of lettuce were significantly reduced at $p < 0.08$. Branch growth, leaf mass, and root growth of poplars were significantly reduced in assessment soils relative to reference soils ($p < 0.05$).

Table 9-5
Phytotoxicity Summary Statistics and
Comparison of Reference and Assessment Endpoints

	Assessment			Reference			Mann-Whitney
Endpoint	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**p-value**
<u>Alfalfa</u>							
Root Length	13	28.5	6.29	10	46.1	6.99	0.121
Root Mass	13	0.015	0.003	10	0.017	0.004	0.804
Shoot Length	13	32.1	4.63	10	60.8	4.31	0.000
Shoot Mass	13	0.042	0.007	10	0.072	0.014	0.121
Total Length	13	60.7	10.55	10	107	10.04	0.011
Total Mass	13	0.058	0.010	10	0.089	0.017	0.154
<u>Lettuce</u>							
Root Length	13	28.7	6.14	10	41.7	3.27	0.107
Root Mass	13	0.012	0.004	10	0.022	0.004	0.072
Shoot Length	13	27.7	4.37	10	53.1	3.90	0.001
Shoot Mass	13	0.042	0.010	10	0.072	0.010	0.055
Total Length	13	56.3	10.33	10	94.9	5.28	0.013
Total Mass	13	0.054	0.013	10	0.094	0.012	0.072
<u>Wheat</u>							
Root Length	14	139	27.01	10	207	8.91	0.219
Root Mass	14	0.016	0.002	10	0.017	0.001	0.861
Shoot Length	14	152	13.40	10	239	5.91	0.000
Shoot Mass	14	0.020	0.002	10	0.032	0.001	0.000
Total Length	14	291	39.94	10	446	13.53	0.005
Total Mass	14	0.036	0.003	10	0.049	0.001	0.007
<u>Poplar</u>							
Branch Growth	7	163	30.83	5	253	11.59	0.012
Leaf Mass	7	3.96	0.79	5	5.81	0.27	0.028
Leaves Added	7	4.26	0.90	5	6.68	0.94	0.327
Root Growth	7	77.8	25.80	5	151	14.11	0.028
Roots Added	7	5.71	2.13	5	8.28	2.29	0.626

For all seeds that germinated, at least minimal growth occurred even in highly contaminated soils. Growth responses were highly variable both within and between species, and no obvious threshold effects were apparent. Correlation analyses indicated that for alfalfa, lettuce, and wheat, root length, stem mass, and stem length, total mass, and total length, and for lettuce, root mass, were significantly negatively correlated with concentrations of lead (Table 9-6).

Table 9-6
Significant Correlation Coefficients (Spearman's rho; $p < 0.05$) Relating Growth Endpoints and Hazardous Substance Concentrations and pH for Alfalfa, Lettuce, and Wheat

Species	Analyte	Root Mass	Root Length	Stem Mass	Stem Length	Total Mass	Total Length
Alfalfa	Arsenic	—	—	—	-0.56	—	—
	Cadmium	—	—	—	-0.62	—	-0.47
	Copper	—	-0.46	—	-0.71	—	-0.64
	Iron	—	—	—	-0.63	—	-0.51
	Manganese	—	—	—	-0.43	—	—
	Lead	—	-0.59	-0.51	-0.83	-0.51	-0.75
	Zinc	—	—	—	-0.61	—	-0.48
	Clay	—	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	—	-0.59	-0.45	-0.83	-0.47	-0.74
	Organic C	—	—	—	0.50	—	—
	pH	—	0.47	—	—	—	—
Lettuce	Arsenic	—	—	—	-0.52	—	—
	Cadmium	—	—	—	-0.49	—	-0.43
	Copper	-0.42	—	-0.45	-0.55	—	-0.49
	Iron	—	—	—	-0.50	—	—
	Manganese	—	—	—	—	—	—
	Lead	-0.60	-0.57	-0.60	-0.68	-0.59	-0.65
	Zinc	—	—	—	-0.45	—	—
	Clay	—	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	-0.48	-0.57	-0.52	-0.73	-0.49	-0.67
	Organic C	—	—	—	0.43	—	—
	pH	—	0.45	—	—	—	—
Wheat	Arsenic	—	—	-0.61	-0.60	—	—
	Cadmium	—	—	-0.63	-0.63	—	—
	Copper	—	—	-0.72	-0.72	-0.49	-0.53
	Iron	—	—	-0.66	-0.64	—	—
	Manganese	—	—	—	-0.42	—	—
	Lead	—	-0.47	-0.83	-0.85	-0.68	-0.71
	Zinc	—	—	-0.64	-0.65	-0.42	-0.42
	Clay	-0.41	—	—	—	—	—
	Sand	—	—	—	—	—	—
	Nitrate	—	-0.57	-0.75	-0.86	-0.61	-0.78
	Organic C	—	—	0.70	0.67	—	0.45
	pH	0.67	0.50	—	—	—	—

— not significant.

Stem length for all three species was significantly negatively correlated with arsenic, cadmium, copper, iron, manganese (except lettuce), and zinc in addition to lead. Correlations with pH (positive) were significant only for alfalfa, lettuce, and wheat root length and wheat root mass, and correlations with organic C, also positive, were significant only for wheat stem mass, stem length, and total length, and alfalfa and wheat stem length. Correlations with percent sand were variable, and with nitrate, predominantly negative. There was a significant negative correlation between clay and wheat root mass; no other correlations with soil texture were significant. Significant correlations with nitrate were negative.

For poplar, branch growth, leaves added, and leaf mass were significantly negatively correlated with lead (Table 9-7). Branch growth and root growth were negatively correlated with nitrate and positively correlated with organic C. No other consistent correlations were observed. Figures 9-7 through 9-10 illustrate relationships between species endpoint responses and lead in soils.

Table 9-7
Significant Correlation Coefficients (Spearman's rho; $p < 0.05$) Relating Soil Metals Properties and Growth Endpoints for Hybrid Poplar

Analyte	Branch Length	Root Length	Number of Leaves Added	Number of Roots	Branch and Leaf Mass
Arsenic	—	—	—	—	—
Cadmium	—	—	—	—	—
Copper	—	—	—	—	—
Iron	—	—	—	—	—
Manganese	—	—	—	—	—
Lead	-0.66	—	-0.60	—	-0.63
Zinc	—	—	—	—	—
Clay (%)	—	—	—	—	—
Sand (%)	-0.63	—	—	—	—
Nitrate	-0.62	-0.59	—	—	—
Organic C	0.65	0.66	—	—	—
pH	—	—	—	0.72	—

— not significant.

The results of the plant growth studies indicate that assessment soils inhibit the growth of multiple plant species, as measured by multiple endpoints. The plant growth reductions were significantly negatively correlated with lead and other hazardous substance concentrations and with nitrate. The nitrate correlation may be more a result of the reduced plant metabolic activity in contaminated soils rather than a cause, since nitrate in a well vegetated, healthy soil is typically assimilated by plants extremely rapidly.

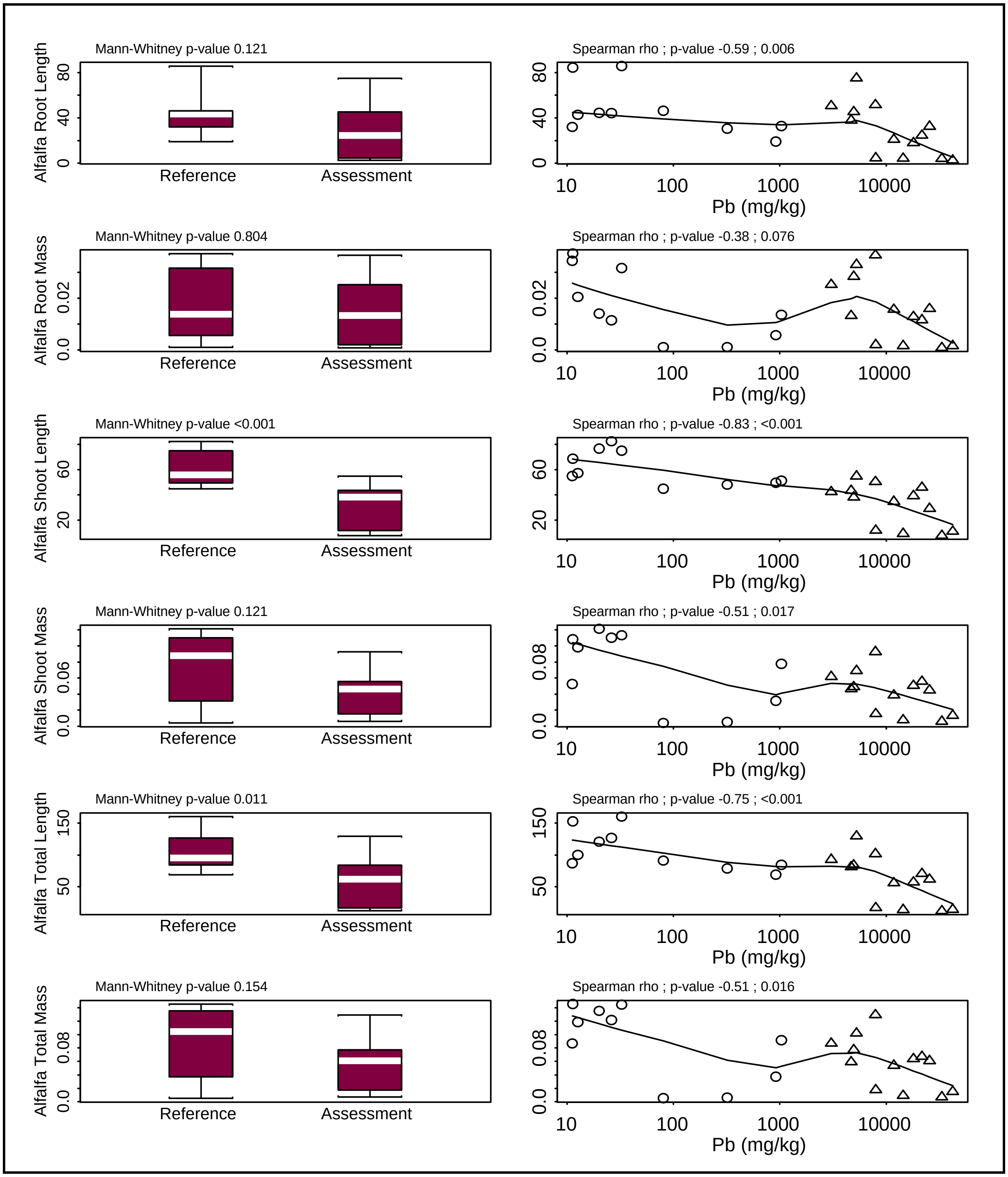

Figure 9-7. Growth responses of alfalfa seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

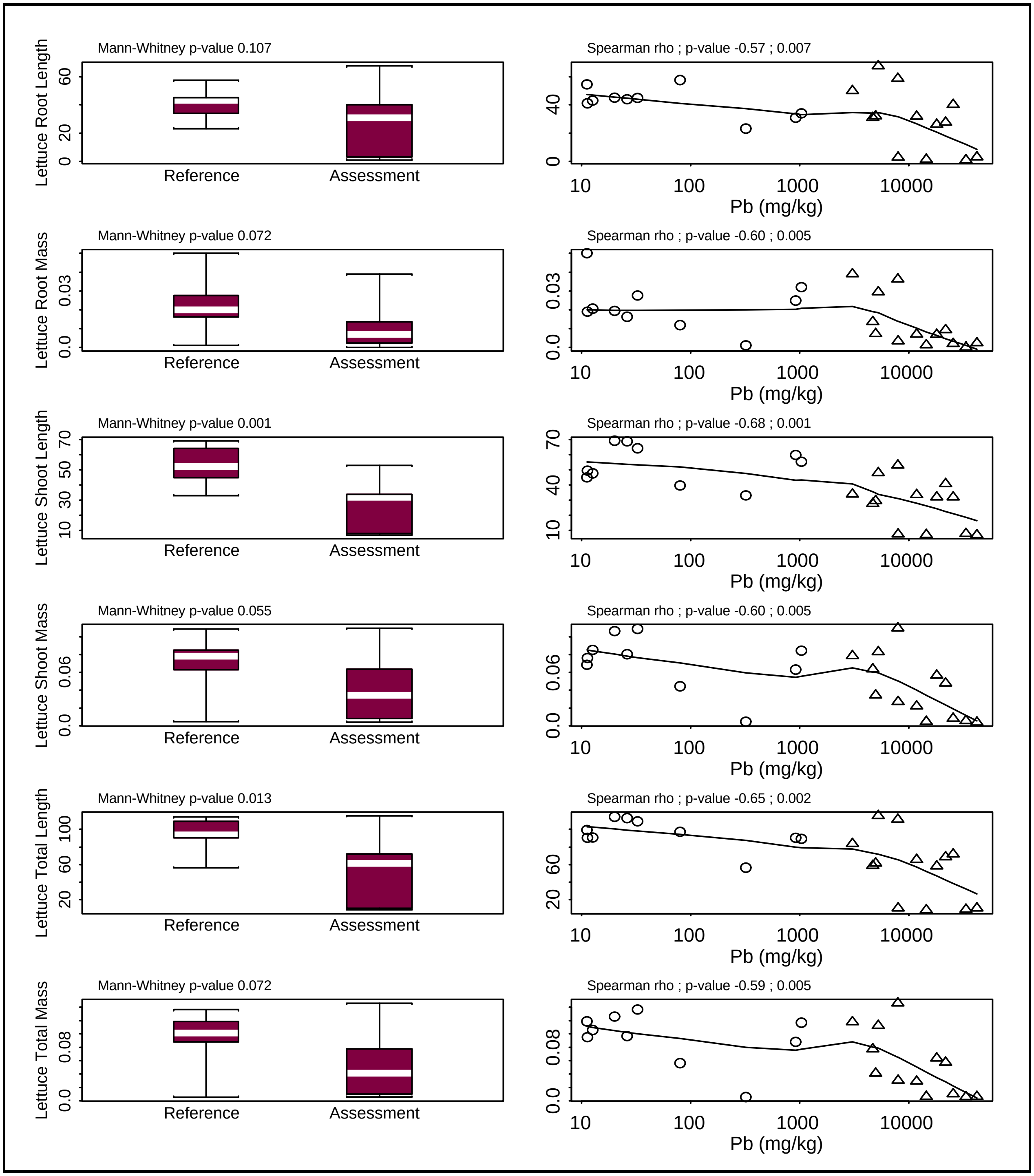

Figure 9-8. Growth responses of lettuce seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

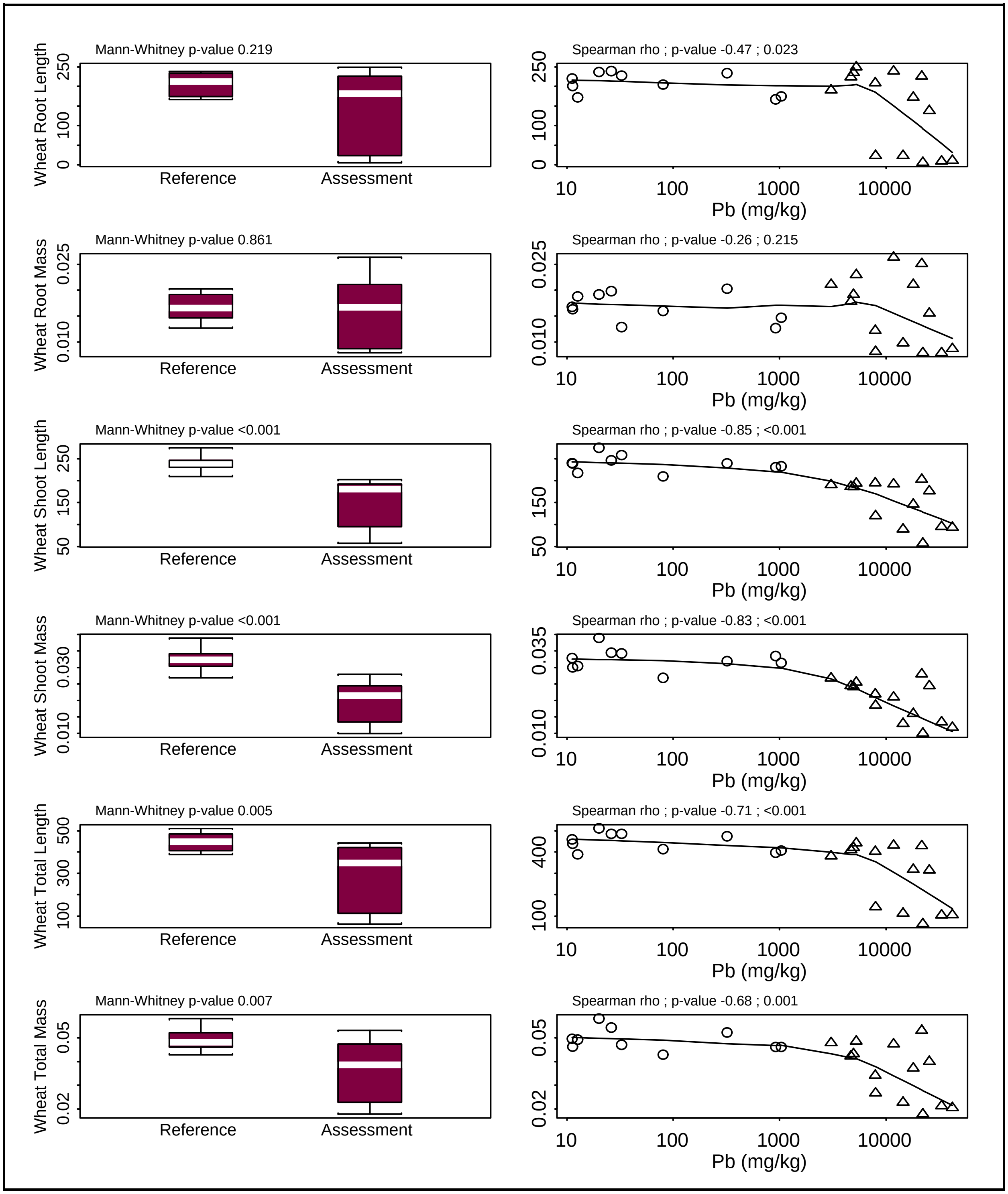

Figure 9-9. Growth responses of wheat seedlings tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression**.**

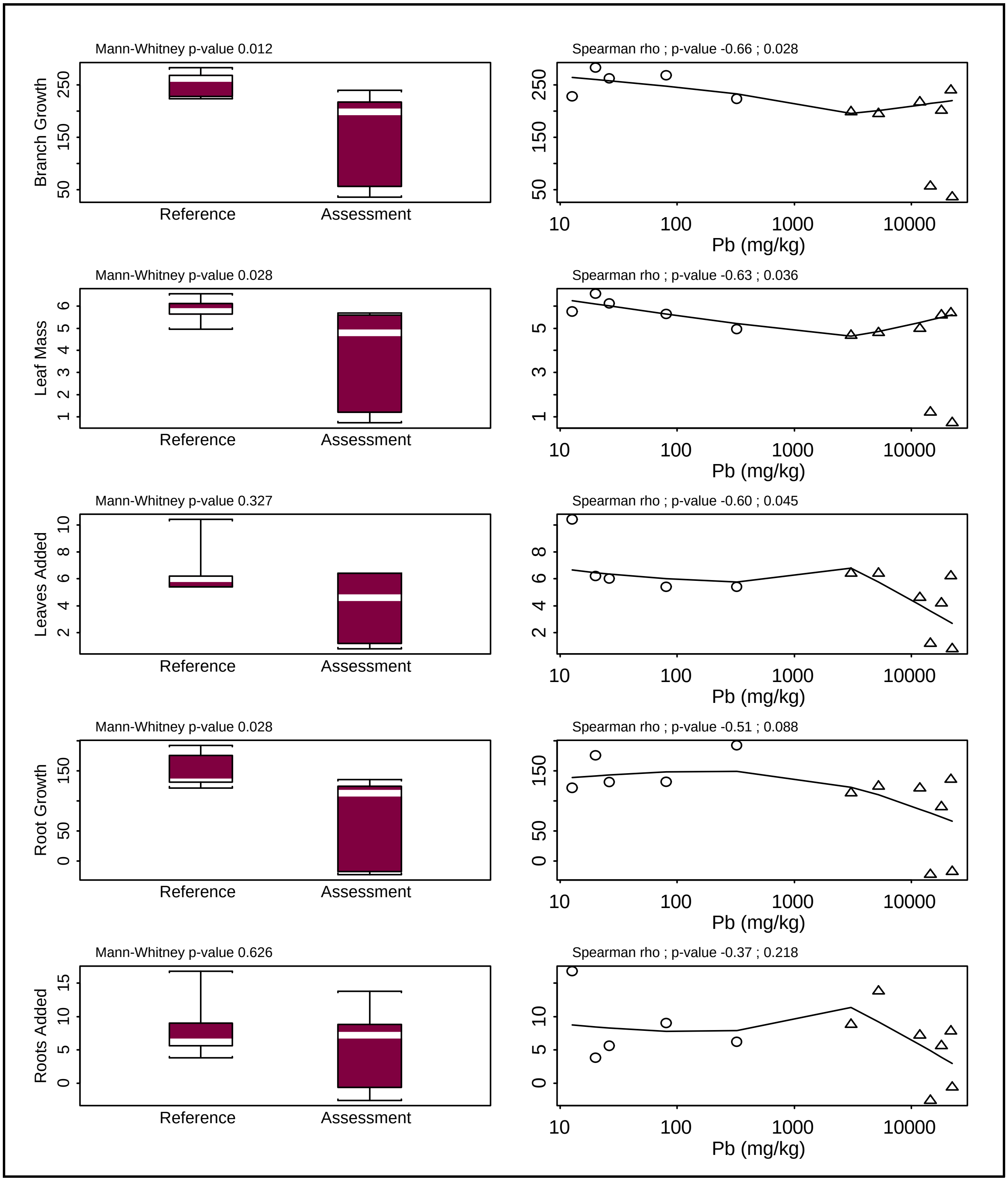

Figure 9-10. Growth responses of poplar tested in soils from upper basin reference areas (circles) and from upper basin assessment areas (triangles) compared to total lead (Pb) in soil. Box plots depict range, median, and interquartile range. Irregular line depicts trend estimated by locally weighted regression.

9.5.3 Field Vegetation Communities

Predominant Cover Type

Of the 107 sites sampled, 78% were classified as predominantly vegetated and 22% were classified as predominantly bare. Bare ground was the dominant cover type at 100% of the Canyon Creek assessment sites, 80% of the Ninemile Creek assessment sites, and 50% of the South Fork Coeur d'Alene River sites. Vegetated cover types were dominant at 100% of the reference sites.

All sites in the lower Coeur d'Alene River basin (n = 44) and on reference reaches in the upper basin (n = 23) were predominantly vegetated. Most of the assessment sites were predominantly barren. A significantly greater percentage of assessment than reference sites was classified as barren on the South Fork Coeur d'Alene River than on the Little North Fork ($p < 0.001$), in the Canyon Creek assessment area than reference area ($p < 0.001$), and in the Ninemile Creek assessment area than reference area ($p < 0.001$) (Table 9-8). Figure 9-11 shows examples of sites that were classified as predominantly vegetated and predominantly barren.

Table 9-8
Vegetated versus Nonvegetated Cover Type Comparisons

Location	Sample Sites with Dominant Cover Type = Vegetation (%)	Sample Sites with Dominant Cover Type = Bare Ground (%)
Reference Areas:		
Little North Fork	100	0
Canyon Creek	100	0
Ninemile Creek	100	0
Assessment Areas:		
South Fork CdA	50	50
Canyon Creek	0	100
Ninemile Creek	20	80
Lower Coeur d'Alene	100	0

The diversity of predominant vegetation types in the upper basin assessment areas was reduced relative to reference areas. Dominant cover types recorded at Little North Fork, Canyon Creek, and Ninemile Creek reference sites included evergreen forest, deciduous forest, deciduous shrubland, and grassland (Figure 9-12). Dominant cover types recorded at South Fork Coeur d'Alene River, Canyon Creek, and Ninemile Creek assessment sites included bare ground, deciduous shrubland, and grassland. In the lower basin, the most common vegetation types were wetlands (48%) and deciduous shrub communities (27%). Two lower Coeur d'Alene sites were grazed or agricultural sites and were omitted from subsequent vegetation analysis.

Figure 9-11. (Top) Predominantly barren riparian zone (South Fork Coeur d'Alene, SF26). (Bottom) Predominantly vegetated riparian zone (Little North Fork Coeur d'Alene, NF03).

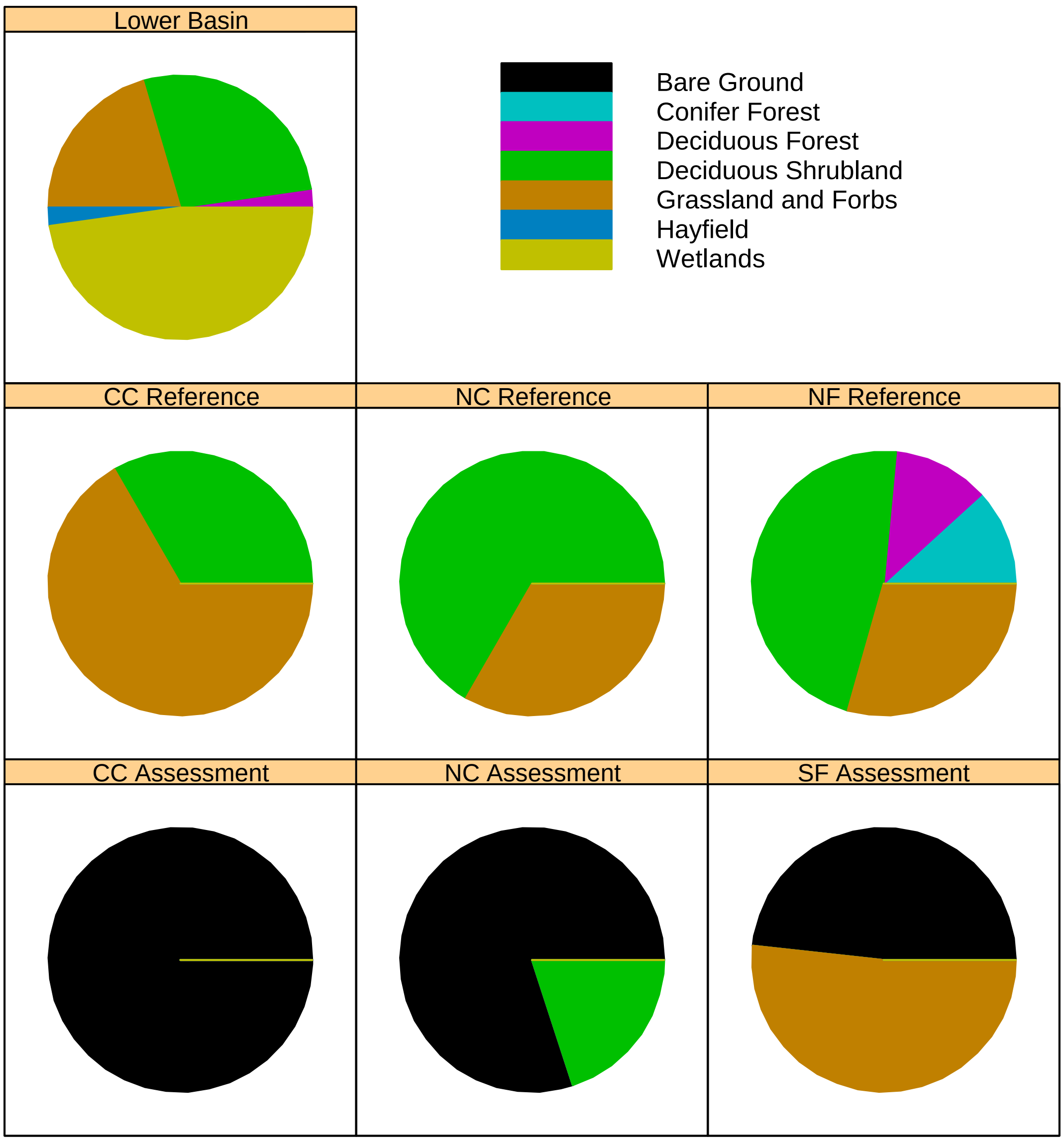

Figure 9-12. Most prevalent cover types in assessment and reference areas.

To confirm the visual estimate of bare ground as a dominant cover type, the line transect data were analyzed to determine the mean proportion of bare ground per site in each of the reference and assessment areas. The mean proportion of bare ground at assessment and reference area sites was compared. The mean bare ground per site was significantly greater ($p < 0.05$) at Ninemile Creek (75.7 %), Canyon Creek (93.5%), and South Fork (47.6%) assessment sites than at Ninemile Creek (5.6%), Canyon Creek (13.1%), and North Fork (4.3%) reference sites. Existing vegetation cover at upper basin assessment sites, even sites classified as predominantly vegetated, is significantly sparser than vegetation cover at reference sites.

Bare ground cover at each site is presented in Figure 9-13. Bare ground at upper basin assessment sites ranged from 0 to 100%, and at reference sites, from 0 to 16%. Bare ground at individual sites in the lower basin ranged from 0 to 72.5% and averaged 10.6%. Of the six assessment sites on Canyon Creek, one site had 31% cover and a second site had 6% cover. The site with 31% plant cover (CC04) included 24% cover by a single species of metals-tolerant grass (redtop, *Agrostis stolonifera*), and 7% cover of moss (Figure 30, Appendix A). Most of the rest of site CC04 (67%) was barren. The site with 6% vegetation cover (CC06) had 6% cover by moss (Figure 32, Appendix A). The rest of site CC06 (94%) was barren. The remaining four of the sites were 100% barren (CC05, CC07, CC08, CC09; Figures 31, and 33 through 35, Appendix A).

Of the five Ninemile Creek assessment sites, one had 23% cover, a second had 35% plant cover, and a third had over 100% plant cover. The site with 23% vegetative cover (NC15) had 23% cover by moss (Figure 39, Appendix A). The site with 35% cover (NC11) had 35% cover by moss (Figure 36, Appendix A). The site with 100% plant cover (NC12) extended from a completely barren section into a patch of alder adjacent to the East Fork Ninemile Creek road. Of the 10 meter transect, 40% was entirely barren. The remaining 60% contained all of the vegetation (Figure 37, Appendix A). The 100% cover score results from overlapping layers of vegetation in the vegetated segment. The remaining two of the five Ninemile Creek sites had no vegetative cover (e.g., Figure NC14).

Although 71% of the South Fork Coeur d'Alene River assessment sites had greater than 50% plant cover, again, the dominant vegetation taxa at South Fork Coeur d'Alene River sites was moss. Moss cover averaged 22% at South Fork Coeur d'Alene River sites. The remaining contributor to any extent was, again, redtop. Figures 1 through 29 in Appendix A show the South Fork Coeur d'Alene River sites. These photographs confirm that the South Fork Coeur d'Alene River sites were predominantly barren.

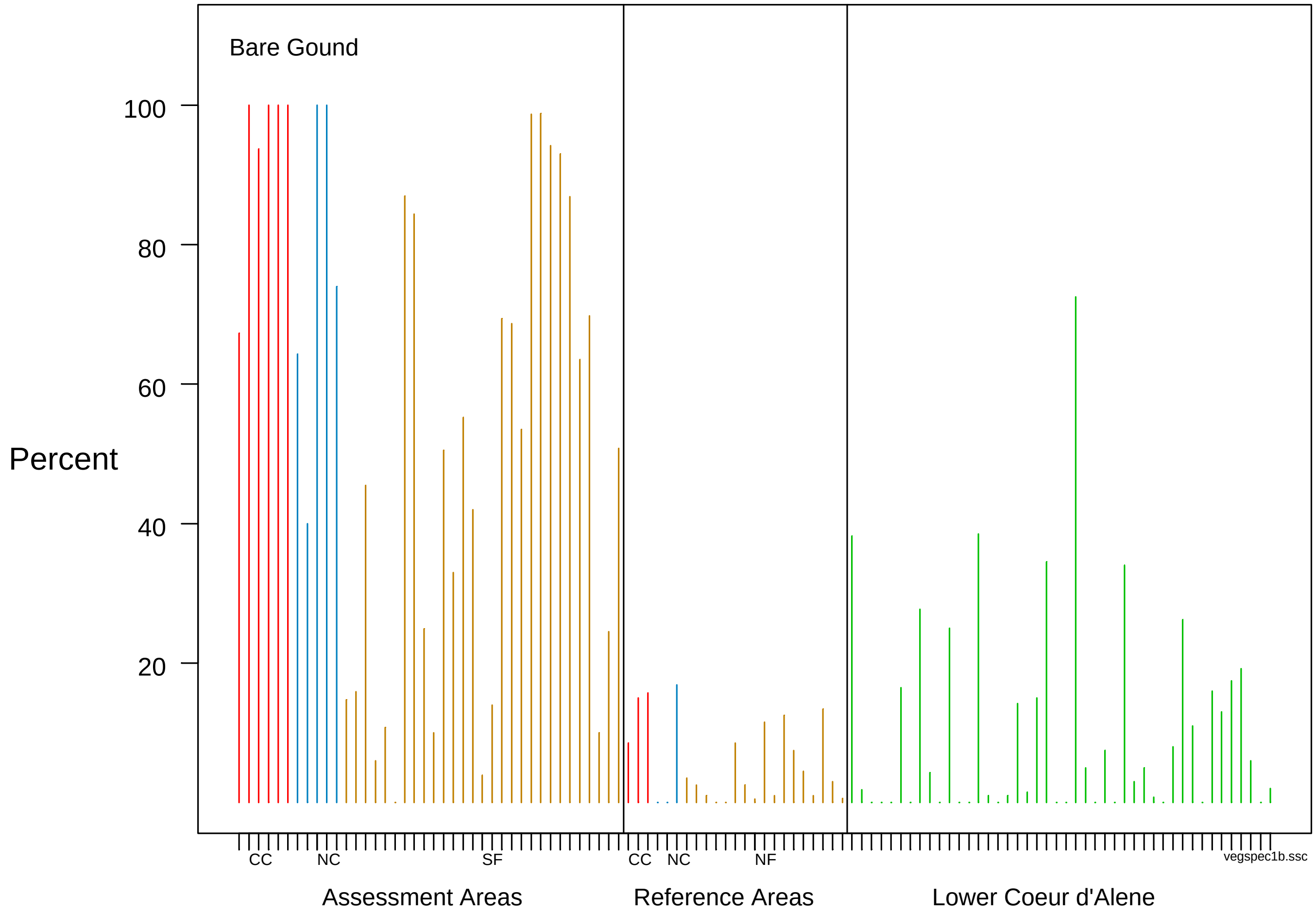

Figure 9-13. Cover of bare ground (meters) measured along a 10 m line transect at each site. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Plant Cover by Height Classification

Significant reductions in percent litter cover, herbaceous cover, and shrub cover were observed at the Ninemile Creek, Canyon Creek, and South Fork assessment sites relative to the reference sites (Table 9-9; Figure 9-14). The total cover (m) in the herbaceous, shrub, tree, and litter layers was significantly greater ($p < 0.05$) at Little North Fork reference sites than at South Fork Coeur d'Alene River assessment sites. The total cover of herbaceous, shrub, and litter layers was significantly greater at Canyon Creek reference sites than at Canyon Creek assessment sites ($p < 0.05$), but no differences were observed in tree canopy cover. Canyon Creek reference sites were predominantly grassland and deciduous shrubland, and Canyon Creek assessment sites were predominantly grassland and bare ground. The total cover of herbaceous and litter layers was significantly greater at Ninemile Creek reference sites than at assessment sites ($p < 0.05$). Cover of the shrub layer was greater at Ninemile Creek reference sites than at assessment sites at $p < 0.1$. No significant difference was observed for the tree layer ($p = 0.197$). Reductions in cover in herbaceous, shrub, tree, and litter layers indicate significant reduction in the vertical composition of vegetation communities at assessment sites.

Table 9-9
Mann-Whitney p-Values for Comparisons of Plant Cover by Layer for Assessment and Reference Sites

Comparison	Herb Cover (m)	Shrub Cover (m)	Tree Canopy Cover (m)	Litter Cover (%)	Bare Ground (%)
North Fork vs. South Fork	0.014[a]	< 0.001[a]	< 0.001[a]	< 0.001[a]	< 0.001[a]
Canyon Creek reference vs. assessment	0.031[a]	0.006[a]	NA	0.011[a]	0.015[a]
Ninemile Creek reference vs. assessment	0.025[a]	0.081	0.197	0.025[a]	0.024[a]

a. Indicates significantly greater cover in the reference area at the 5% level.
NA — not analyzed — tree cover recorded on one site only.

Figure 9-15 shows the cover by individual site of each vegetation in the herbaceous, shrub and tree layers. Cover in the tree and shrub layers was extremely low or absent at all upper basin assessment sites. Cover in the tree and shrub layers in the reference areas was variable, but considerably greater at reference areas than assessment areas. Herbaceous cover at assessment sites was also low relative to reference sites. Lower Coeur d'Alene sites lacked tree cover, and shrub cover was present at some sites but absent at others. Herbaceous cover at lower Coeur d'Alene sites was dense.

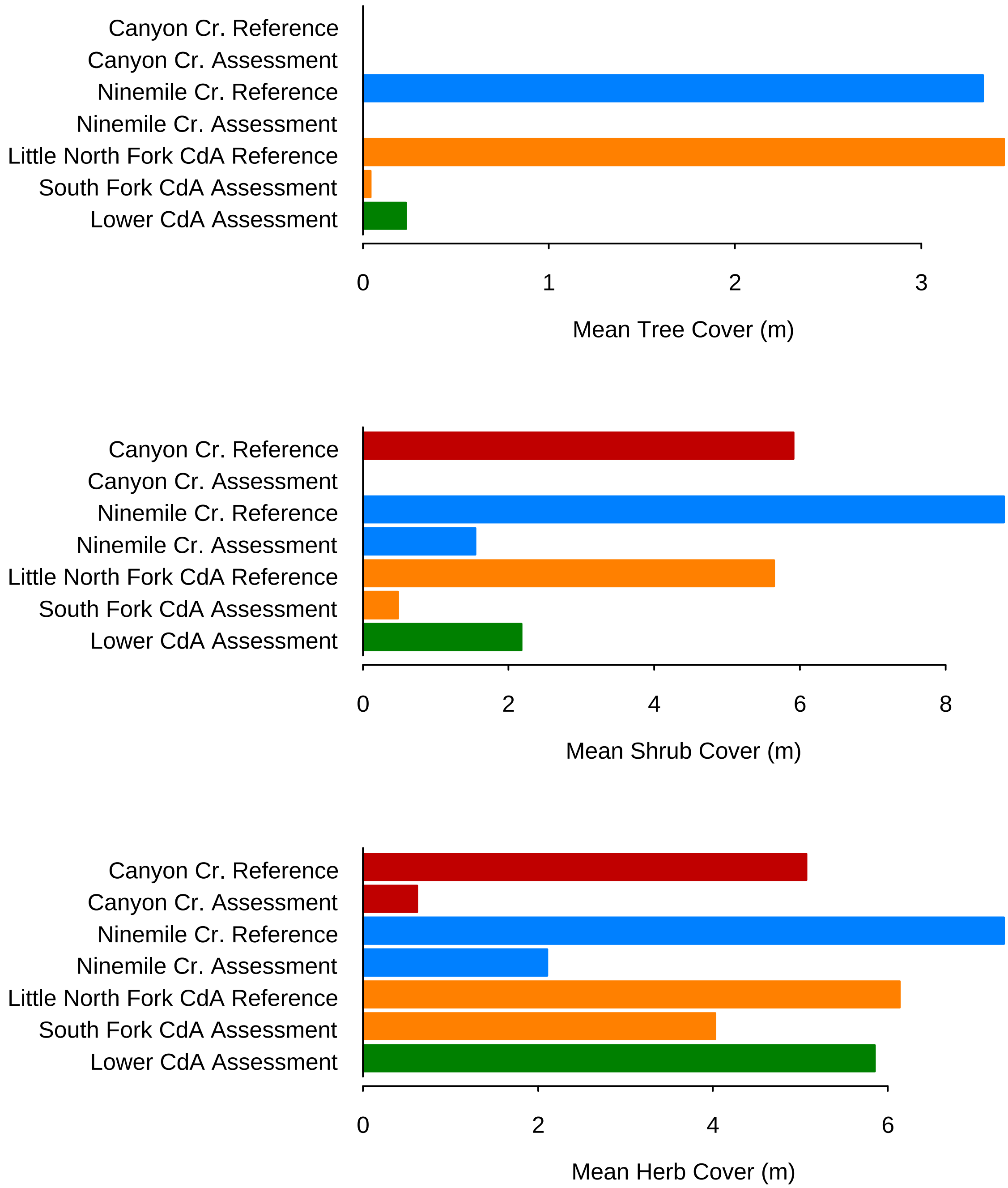

Figure 9-14. Mean tree cover, shrub cover, and herbaceous vegetation cover (m) at assessment and reference areas.

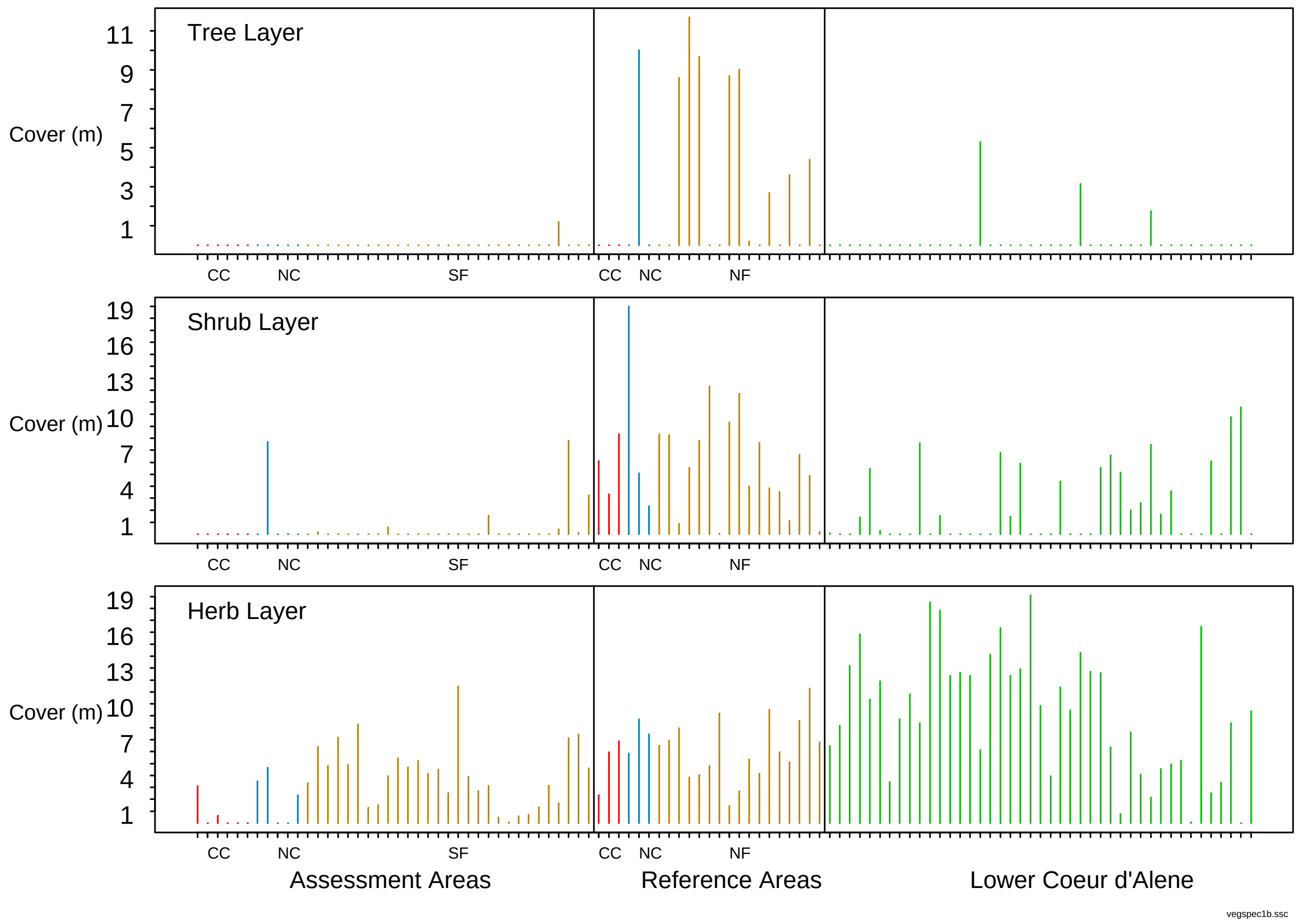

Figure 9-15. Cover (meters) in the tree, shrub, and herbaceous layers at each of the sample sites. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Species Richness

Across the assessment and reference sites, 172 vascular species were identified. In the herbaceous layer, 149 taxa, most to the species level, were identified. In the shrub layer, 54 taxa, again, most to the species level, were identified, and in the tree layer, 8 species were identified. Since the sampling was conducted in late summer, the herbaceous totals do not include spring ephemeral species that might be present. The maximum number of species identified at a single site was 25; most sites had fewer than 10. Sites on reference reaches of the upper basin had significantly greater overall species richness and species richness in the herbaceous and shrub layers than sites on assessment reaches. Tree species richness was low at all sites.

The majority of the vascular species identified were uncommon. Sixty-six (38%) were found only at one site, and 95% were found on fewer than 10% of the sites. The most frequently encountered species in the herbaceous layer were the graminoids redtop bentgrass (*Agrostis stolonifera*), reed canarygrass (*Phalaris arundinacea*), red tinge bullrush (*Scirpus microcarpus*), and tufted hairgrass (*Deschampsia cespitosa*), and the forbs cow parsnip (*Heracleum lanatum*), northern water hore-hound (*Lycopus uniflorus*), and pioneer violet (*Viola glabella*). The most frequently encountered species in the shrub layer were thinleaf alder (*Alnus incana*), Douglas' meadow sweet (*Spiraea douglasii*), mallow-leaf ninebark (*Physocarpus malvaceus*), common snowberry (*Symphoricarpos alba*), and sitka willow (*Salix stichensis*). Black cottonwood (*Populus trichocarpa*) and grand fir (*Abies grandis*) were the most common of the tree species. Moss (taxa not identified) was recorded at 62% of the sites.

Table 9-10 presents the most frequently encountered vascular plant species in the upper and lower basins by layer. For the upper basin sites, species representation is presented by assessment area and reference area. Species representation at upper basin assessment sites was dominated by redtop bentgrass (present at 70% of sites). All other species that were common at reference sites in the herbaceous, shrub, and tree layers were absent or poorly represented at the assessment sites. The riparian vegetation of the upper basin assessment sites is compositionally and structurally depauperate relative to the reference sites.

The number of species by site and the number of species within each habitat layer by site were analyzed to quantify relative differences in community composition between assessment and reference areas. Figure 9-16 presents the total number of species by layer at each of the assessment and reference sites. The numbers of species in the tree layer, shrub layer, and herb layer were considerably lower at upper basin assessment sites than at reference sites. Species richness at upper basin reference sites was also generally greater than at lower Coeur d'Alene sites. In Canyon Creek, 39 species were recorded at the three reference sites sampled; 2 species were recorded at the six assessment sites. In Ninemile Creek, 52 species were recorded at the three reference sites; 14 species were recorded at the five assessment sites. At Little North Fork reference sites, 106 species were recorded at the 17 sites sampled, while at the South Fork assessment sites, 35 species were recorded at 29 sites sampled. At lower Coeur d'Alene basin reference sites, 89 species were identified.

Table 9-10
Vascular Plant Species Frequency by Layer, Upper and Lower Coeur d'Alene River Basin[a]

Upper Basin	% of Sites Reference	% of Sites Assessment	Lower Basin	% of Sites
Herbaceous Layer			Herbaceous Layer	
Agrostis stolonifera	34	70	*Phalaris arundinacea*	41
Phalaris arundinacea	52	0	*Agrostis stolonifera*	36
Heracleum lanatum	43	0	*Scirpus microcarpus*	23
Viola glabella	39	0	*Lycopus uniflorus*	20
Tanacetum vulgare	39	2.5	*Sagitaria latifolia*	18
Carex deweyana	35	0	*Scirpus cyperinus*	18
Dactylis glomerata	17	15	*Deschampsia cespitosa*	16
Achillea millefolium	30	0	*Sparganium emersum*	14
Festuca subulata	30	0	*Lemna minor*	14
Plantago laceolata	26	2.5	*Eleocharis acicularis*	14
Poa compressa	22	5	*Carex vesicaria*	14
Shrub Layer			Shrub Layer	
Physocarpus malvaceus	48	0	*Spiraea douglasii*	32
Alnus incana	39	5	*Alnus incana*	16
Symphoricarpos albus	35	0	*Salix drummondii*	7
Rhamnus purshiana	26	0	*Crataegus douglasii*	7
Salix stichensis	26	0	*Cornus stolonifera*	7
Tree Layer			Tree Layer	
Populus trichocarpa	35	2.5	*Populus trichocarpa*	5
Abies grandis	35	0	*Betula occidentalis*	2

a. Species presented are the 11 most common in the herbaceous layer, 5 most common in the shrub layer, and 2 most common in the tree layer.

Species richness in herbaceous and shrub layers is significantly reduced in the upper basin assessment areas relative to reference areas (Table 9-11). Where vegetation exists in the upper basin assessment area, the community is strongly dominated by a small number of species. At upper basin assessment areas, vegetation cover is strongly dominated by moss and *Agrostis stolonifera*. Six sites in the Smelterville Flats area support sparse cover of festuca (*Festuca ovina* and *Festuca* sp.) and orchardgrass (*Dactylis glomerata*). These species most likely remain from earlier revegetation trials (U.S. BLM, 1992, 1993; Section 9.3.2). Other species that occurred at more than two assessment sites include field horsetail *(Equisetum arvense*) at three sites and spotted knapweed (*Centaurea maculosa*), a noxious weed, at four sites. In reference areas and at lower Coeur d'Alene sites, dominance of a site by a single species is less common, and a much greater number of subdominant and rare species are present.

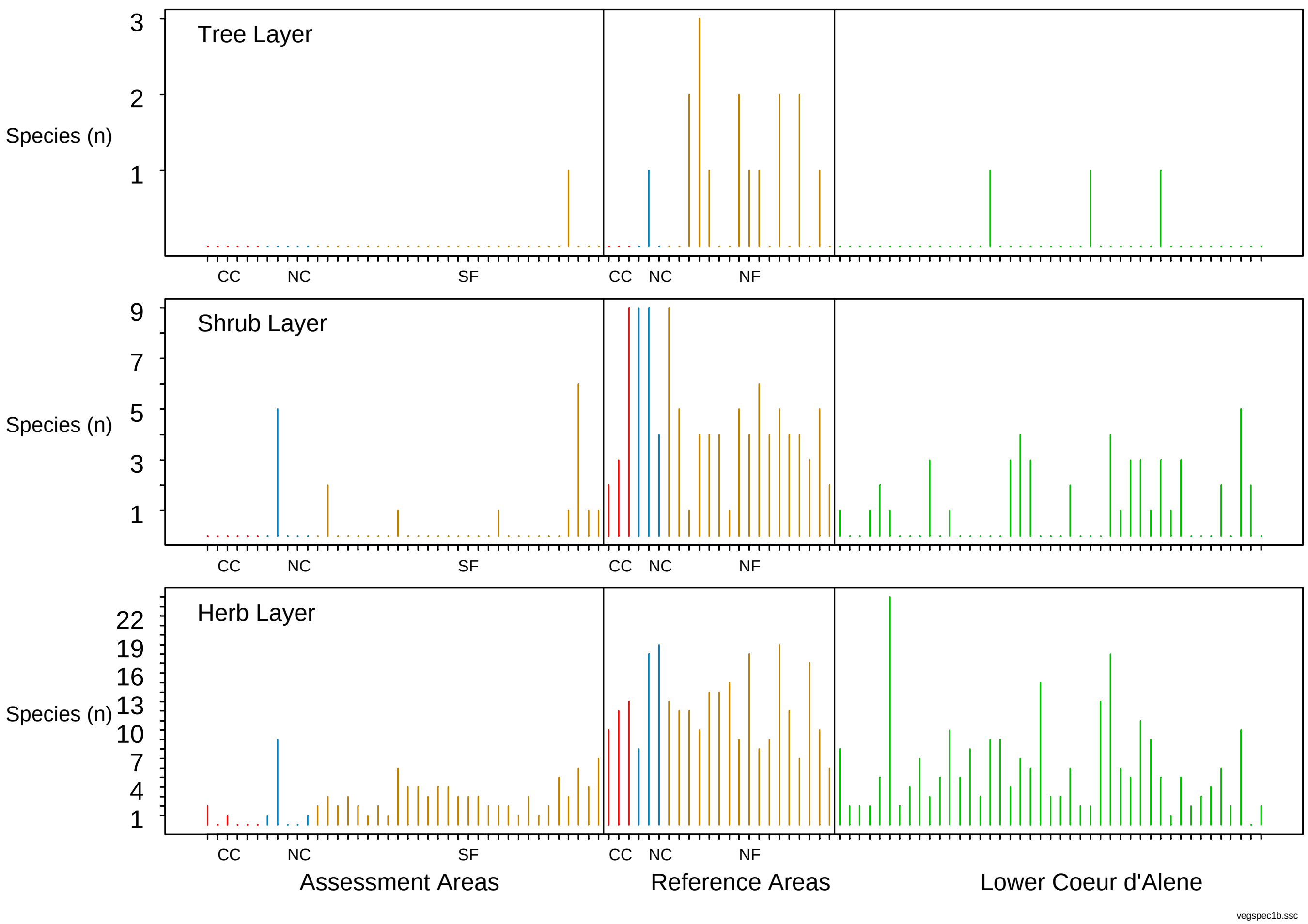

Figure 9-16. Number of species in the tree, shrub, and herbaceous layers at each of the sample sites. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

Table 9-11
Mann-Whitney p-Values for Comparisons of Species Richness by Layer in Upper Basin Assessment and Reference Areas

Comparison	Number of Species: Herbaceous Layer	Number of Species: Shrub Layer
North Fork vs. South Fork	< 0.001[a]	< 0.001[a]
Canyon Creek assessment vs. reference	0.015[a]	0.006[a]
Ninemile Creek assessment vs. reference	0.050[a]	0.015[a]

a. Indicates that the reference area has a significantly greater species richness than the assessment area at $p \leq 0.05$.

The species richness data indicate substantial and statistically significant reductions in the number of species at upper basin assessment sites. The reductions are apparent in the herbaceous, the shrub, and overstory components of the vegetation community. The assessment sites are compositionally and structurally simplified relative to reference vegetation communities. Moreover, the only common species at the assessment sites (redtop bentgrass) is a species previously reported to be metals-tolerant (Chaney, 1993).

Structural Habitat Complexity

Significant differences were observed between the number of structural habitat layers at Ninemile Creek assessment and reference sites, and between the number of structural habitat layers at Little North Fork and South Fork Coeur d'Alene River sites (Figure 9-17). Both the Ninemile Creek reference sites and the Little North Fork sites were vertically complex: the Ninemile Creek reference sites each supported four layers: tree canopy, shrub midstory, understory, and terrestrial subsurface layers. The Little North Fork sites supported from three layers at 35% of the sites to five layers at 47% of the sites. The Lower Coeur d'Alene sites supported from two to five layers; 52% of sites had three layers (mainly shrub midstory, understory, and terrestrial subsurface layers), and 30% had two layers (mainly understory and terrestrial subsurface layers).

All of the assessment sites were vertically simple in comparison to the Little North Fork and Ninemile Creek reference sites. The number of habitat layers at South Fork Coeur d'Alene River sites ranged from zero to four, but the majority of the sites supported either one (41%) or two (41%) habitat layers. The number of habitat layers in the Ninemile Creek assessment area ranged from zero at 40% of the sites, to three at 20% of the sites, and in the Canyon Creek assessment area, from zero at 50% of the sites, to two at 17% of the sites (Figure 9-18).

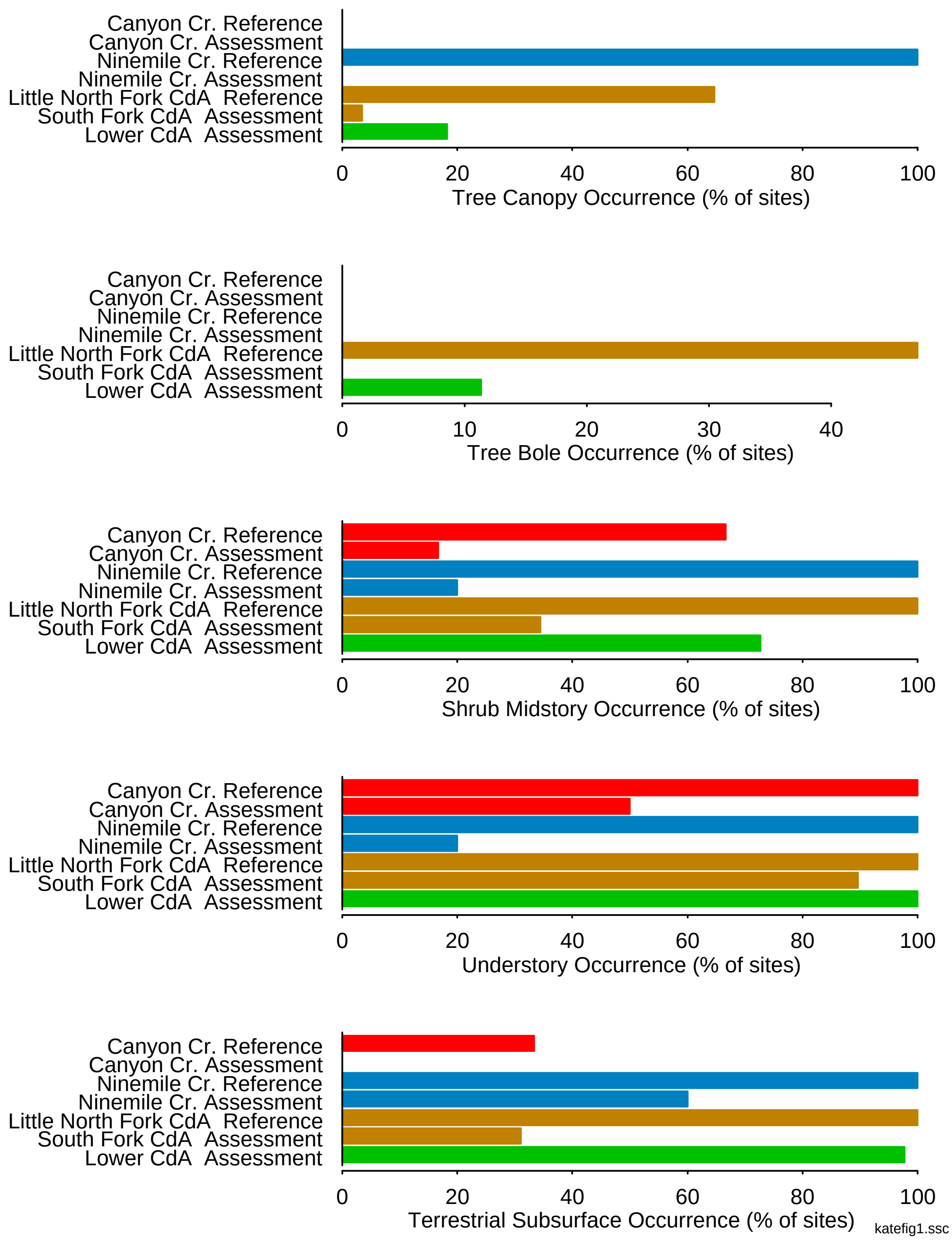

Figure 9-17. Percent of sites at which the following habitat layers were present within a 10 m radius of the site center: tree canopy, tree bole (trunk), shrub midstory, understory, terrestrial subsurface.

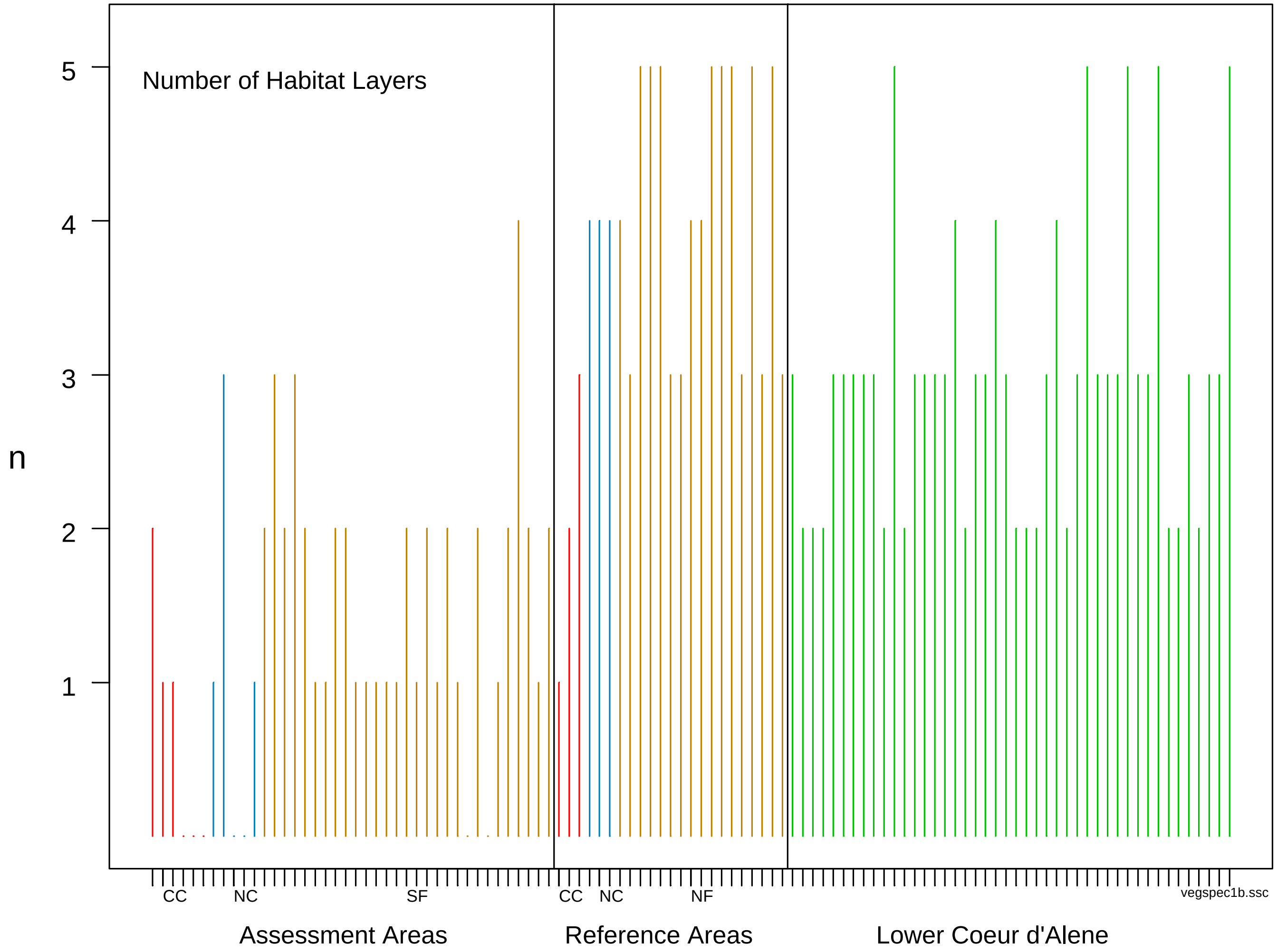

Figure 9-18. Number of habitat layers by site. Maximum number of layers at a site = 5. CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

The number of habitat layers at sites in the Canyon Creek assessment area was not significantly different from the number of layers at sites in the reference area. Of the reference sites, the upstream-most site had the lowest concentrations of hazardous substances, and the downstream-most site had the highest concentrations of hazardous substances. With an increase in concentrations of hazardous substances, a reduction in vertical complexity was apparent. A similar pattern was observed for a number of species and cover of shrub species.

The habitat layers present at the assessment sites are predominantly understory or terrestrial subsurface (Figure 9-17). In the Little North Fork and Ninemile Creek reference areas, tree canopy, tree bole (Little North Fork only), shrub midstory, understory, and terrestrial subsurface were present at most of the sites. The South Fork Coeur d'Alene River assessment area supported tree canopy at one site, terrestrial subsurface and shrub midstory at approximately 40% of the sites, and understory at 90% of the sites. In the Ninemile Creek assessment area, terrestrial subsurface was present at 60% of the sites, and shrub midstory and understory at only 20% of the sites. In Canyon Creek shrub midstory, understory, and terrestrial subsurface layers were represented at reference sites, and shrub midstory and understory at assessment sites.

In general, the quality and availability of riparian wildlife habitat (as indexed by vegetation structural complexity) have been reduced in upper basin assessment areas relative to reference areas. Niche space provided by tree canopy and tree bole is absent in the upper basin assessment areas and most lower Coeur d'Alene assessment sites. Tree canopy and tree bole layers were also absent at Canyon Creek reference sites. Niche space provided by the shrub midstory, understory, and terrestrial subsurface is reduced in upper basin assessment areas relative to reference areas. In the lower Coeur d'Alene, habitat provided by the shrub midstory may also be reduced.

Reduction in the vertical complexity of vegetation communities reduces both the quantity of available habitat space for wildlife and the quality of the habitat. Habitats that are structurally complex (i.e., have many habitat layers) generally support a more diverse fauna than structurally simple habitats, as has been shown for birds (MacArthur and MacArthur, 1961; Cody, 1975; Mosconi and Hutto, 1982; Sanders and Edge, 1998), reptiles (Pianka, 1967), fish (Tonn and Magnuson, 1982), and mollusks (Harman, 1972). Riparian vegetational complexity is also associated with increased avian abundance, species richness, and landscape-level biological diversity (Knopf and Samson, 1994; Sanders and Edge, 1998).

9.5.4 Relationship between Soil Metals and Field Vegetation

The analyses described below address the acceptance criterion at 43 CFR 11.62 (f)(2)(ii), which requires that documentation of an injury response in free-ranging organisms (field vegetation) include the correlation of the degree of the biological response to the observed exposure concentration of hazardous substances.

Correlation analysis was conducted to evaluate univariate relationships between measures of vegetation composition and structure and concentrations of hazardous substances and other parameters in soils. For the upper Coeur d'Alene sites, percent cover of vegetation by layer, number of species by layer, and number of habitat layers are significantly negatively correlated ($p < 0.05$) with concentrations of arsenic, cadmium, copper, iron, lead, manganese, and zinc (Table 9-12). Percent cover of bare ground was positively correlated with metals and arsenic concentrations.

Table 9-12
Significant Correlation Coefficients (Spearman's rho; p < 0.05) Relating Field Vegetation Measurements and Soil Chemistry

	As	Cd	Cu	Fe	Mn	Pb	Zn	Sand	Clay	Org. C
Upper Coeur d'Alene Sites										
Herbaceous Layer (m)	-0.25	-0.27	-0.28	-0.26	-0.18	-0.42	-0.30	-0.46	0.38	0.54
Shrub Layer (m)	-0.69	-0.70	-0.67	-0.71	-0.64	-0.68	-0.71	-0.38	0.47	0.66
Tree Layer (m)	-0.45	-0.46	-0.46	-0.48	-0.44	-0.46	-0.47	-0.27	0.35	0.40
Herbaceous Species (#)	-0.61	-0.60	-0.60	-0.58	-0.49	-0.69	-0.61	-0.42	0.42	0.67
Shrub Species (#)	-0.67	-0.71	-0.66	-0.70	-0.64	-0.69	-0.70	-0.42	0.49	0.69
Tree Species (#)	-0.45	-0.46	-0.45	-0.48	-0.44	-0.46	-0.47	-0.26	0.34	0.38
Bare Ground (%)	+0.44	+0.48	+0.52	+0.49	+0.43	+0.66	+0.53	0.59	-0.54	-0.69
Layers (#)	-0.55	-0.64	-0.68	-0.62	-0.54	-0.74	-0.67	-0.39	0.44	0.60
Lower Coeur d'Alene Sites										
Herbaceous Layer (m)	-0.52	-0.36	-0.49	-0.53	-0.49	-0.47	-0.37	—	—	0.51

— not significant.

No significant correlations were detected between field vegetation measures and pH. Significant positive correlations between pH and plant growth measures were detected in laboratory studies. However, the field vegetation data incorporate multiple species and lifestage responses to pH and gradients of, for example, water availability, light availability, physical disturbance, and temperature fluctuations. Given that soil pH at the majority of the sites sampled was within the range of pH that is conducive to plant growth, it is not surprising that at the vegetation community level, a significant correlation was not detected. Field vegetation measures were significantly positively correlated with percent clay and organic carbon, and negatively correlated with percent sand. Bare ground was positively correlated with percent sand, and negatively correlated with percent clay and organic carbon.

For the lower Coeur d'Alene sites, a significant negative relationship was detected between cover in the herbaceous layer and arsenic and all metals concentrations. A significant positive correlation was detected between cover in the herbaceous layer and percent organic carbon. No other significant positive or negative relationships were detected (Table 9-12).

To evaluate multivariate relationships between soil chemical quality and the composition and structure of field vegetation, soil groupings based on principal components analysis (PCA) and vegetation classifications using structural and compositional attributes were compared. PCA is a standard ordination technique used to identify linear combinations of variables that best explain the variation in a set of data with multiple attributes, such as measures of multiple soil metals concentrations (Gauch, 1982). Variables used in the soil PCA included standardized concentrations of arsenic, cadmium, copper, iron, manganese, lead, and zinc.

As a result of the PCA, sites were ordinated along two axes that explained 91% of the variation in the data set. The axes represent increasing concentrations of all metals and increasing divergence in metals concentrations (high concentration of some, low concentrations of others). Figure 9-19 shows the ordination of sites along principal component axes. At the origin is a cluster of sites, including the reference sites and some lower Coeur d'Alene sites. Assessment sites are scattered in the directions of increasing total metals concentration and increasing variability in metals concentrations. Sites were grouped into categories of metals enrichment and variability based on visual inspection of their distribution in Figure 9-19.

Cluster analysis was used to classify sites by similarity of vegetation structure. Cluster analysis is a standard classification technique used in vegetation analysis to group similar vegetation units (usually sample sites or communities) based on similarity of multiple attributes of the units (Gauch, 1982). In this case, a hierarchical classification technique was used to arrange groups of similar sites into nested groups. Variables used in the cluster analysis included total cover of vegetation, cover in the herbaceous layer, cover in the shrub layer, number of layers present, total number of species, number of herbaceous species, and number of shrub species. These variables were selected based on the measured reduction in structural and compositional heterogeneity downstream of major mining related disturbance. Multivariate analysis of vegetational attributes is presented for upper basin sites only. Since the univariate relationships between field vegetation in the lower basin and soil chemistry were nonsignificant (except for the negative correlations between metals concentrations and cover in the herbaceous layer), the remainder of the vegetation data analysis focused on the upper basin.

Four clusters were retained based on the cluster group means for each input variable and consideration of the level of grouping that was most ecologically meaningful (Figure 9-20). The resulting clusters include three exhibiting relatively complex structure and one in which cover, species richness, and number of layers were low. Sites in cluster A (Figure 9-20) generally are dominated by species-rich herbaceous vegetation surrounded by shrub and tree layers, such as meadows in riparian forest or shrubland. Sites in cluster B are shrub dominated and species rich, and they have the highest total cover. Sites in cluster C are dominated by herbaceous vegetation with lower diversity and cover than sites in cluster A. Sites in cluster D have low species richness in herbaceous and shrub layers; low herbaceous, shrub, and total cover; and low structural diversity.

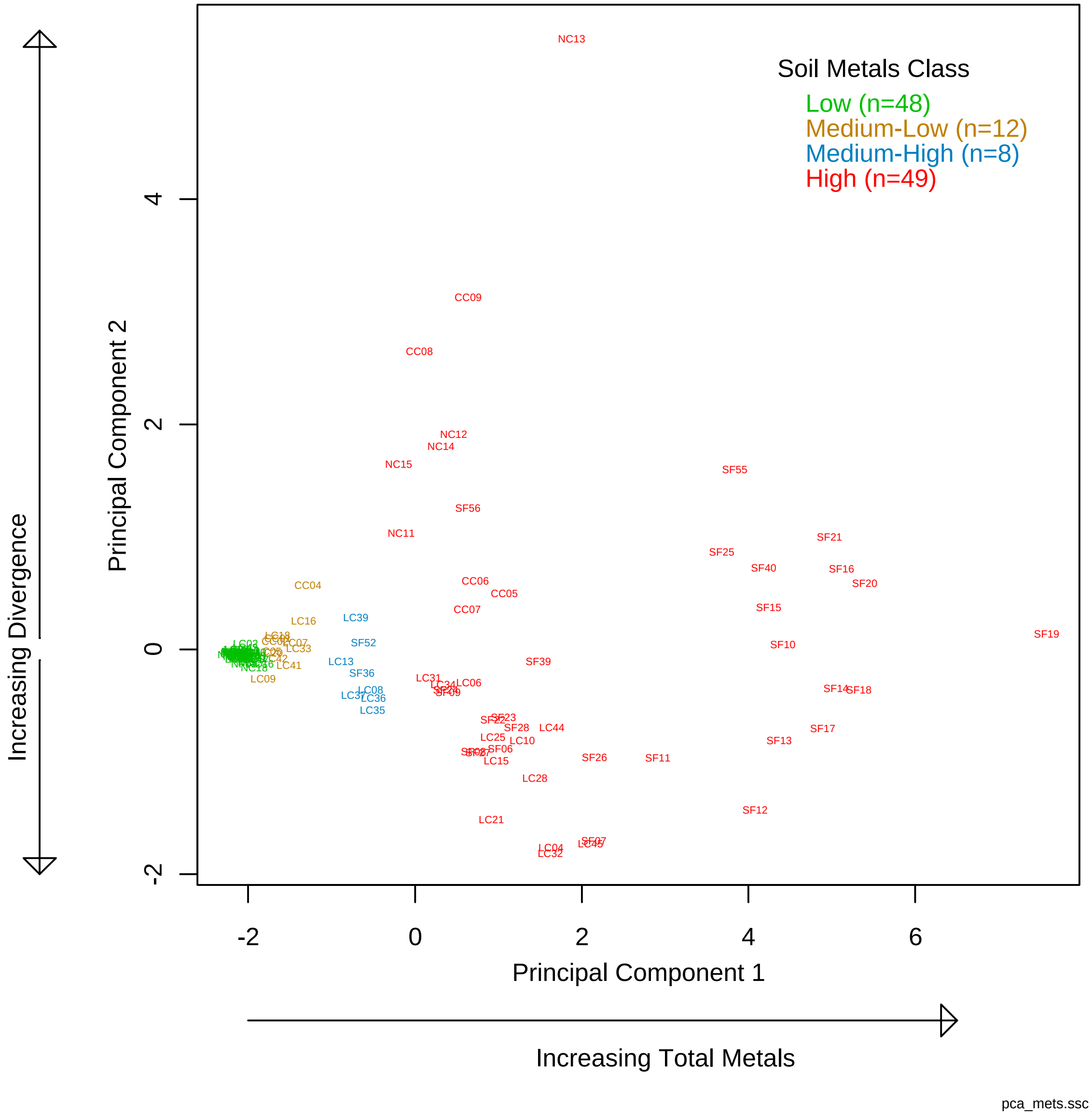

Figure 9-19. Ordination of sample sites based on principal components analysis of metals and arsenic concentrations in soils. Axes represent increasing total metals concentration and increasing divergence in metals concentrations. Sites were grouped into soil metals classes based on visual inspection of their distribution along the two axes. The cluster of points near the origin are sites with low metals concentrations. The cluster includes the reference sites and some of the Lower Coeur d'Alene sites.

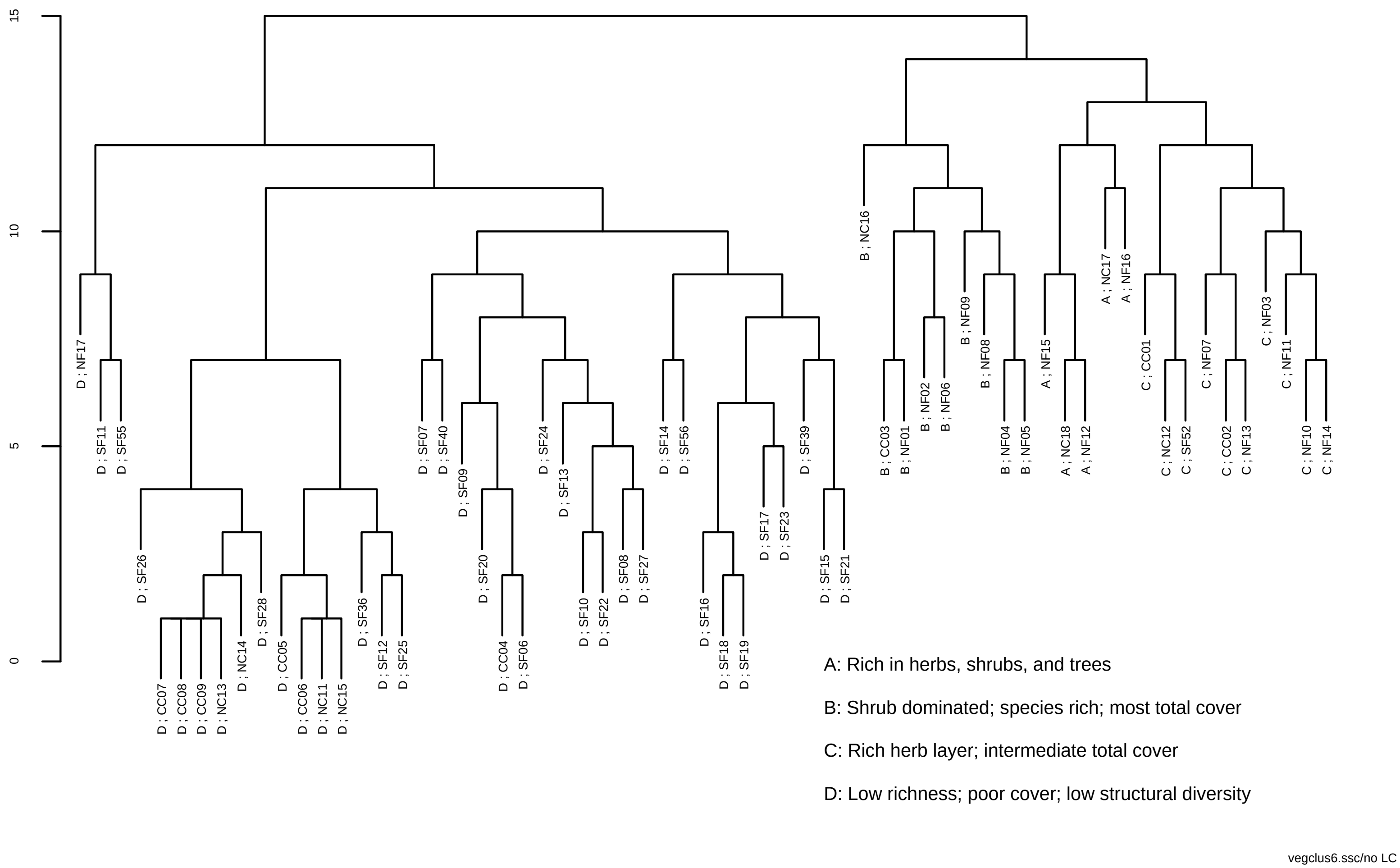

Figure 9-20. Dendrogram illustrating clusters of sites based on vegetation complexity measures. Letters preceding site identification codes indicate cluster group (A to D). CC: Canyon Creek; NC: Ninemile Creek; SF: South Fork Coeur d'Alene River; NF: Little North Fork.

These clusters classify sites with generally similar vegetation community attributes. As an independent check on the appropriateness of the cluster groups, a principal components analysis was conducted using the same input variables. The PCA produced an ordination of sites consistent with the cluster groups (not shown).

Table 9-13 shows the relationship between soil categories and vegetation structure clusters. Soil categories range from “low metals” (soils with low metals concentrations and low variability among standardized metals concentrations) to “high metals.” Vegetation clusters include the three high complexity clusters and the low complexity cluster. The reference sites are all grouped in the “low metals” row, and most reference sites are grouped in a structurally and compositionally rich cluster. The majority of the assessment sites were categorized as “high metals” and were clustered in the structurally simple group. The relationship shown in Table 9-13 of structural simplicity where metals concentrations are high is consistent with the univariate correlation analysis results in Table 9-12.

Table 9-13
Relationship Between PCA Soil Categories and Vegetation Structure Clusters for Upper Basin Assessment and Reference Sites

Soil Category	Vegetational Structural Complexity			
	Structurally Complex			Structurally Simple
Low Metals	NF12 NC17 NF15 NC18 NF16	NF01 NF05 NF09 NF02 NF06 CC03 NF04 NF08 NC16	NF03 NF11 NC12 NF07 NF13 NF10 NF14	NF17
Medium-Low Metals			CC01 CC02	CC04
Medium-High Metals			SF52	SF36
High Metals				SF06 SF14 SF22 SF40 NC11 SF07 SF15 SF23 SF55 NC12 SF08 SF16 SF24 SF56 NC13 SF09 SF17 SF25 CC05 NC14 SF10 SF18 SF26 CC06 NC15 SF11 SF19 SF27 CC07 SF12 SF20 SF28 CC08 SF13 SF21 SF39 CC09

All but two of the upper basin reference sites were categorized as structurally complex, and all but two had low metals concentrations. All but two of the upper basin assessment sites were categorized as structurally simple, and none had low metals concentrations. The great majority of upper basin assessment sites had common attributes of high metals concentrations and low species richness and cover in herbaceous and shrub layers. Table 9-13 shows the high degree of correspondence of the vegetationally simple sites, categorized as such based on numerous vegetation attributes, with the sites where soils are metals-enriched.

Figures 9-21 and 9-22 show the species composition and cover by layer (herbaceous layer and shrub layer) by site, for each of the four clusters. Species that occurred at fewer than two sites were omitted from these figures. The triangles indicate cover less than 10% of the total vegetation cover at the site, and the circles represent cover greater than 10% of the total vegetation cover at the site. The colors represent soil cluster type: red indicates sites with "low metals" soils, green indicates sites with "medium-low metals" soils, brown indicates sites with "medium-high metals" soils, and blue indicates sites with "high metals" soils. Figures 9-21 and 9-22 show that sites in the structurally simple cluster (D), which included the majority of the upper basin assessment sites, were compositionally simple (low species richness), had sparse cover in the herbaceous and shrub layers relative to sites in the remaining three clusters (A-C), and, except for a single site at the mouth of the Little North Fork, had metals enriched soils. The sites with high concentrations of metals in soils (blue symbols) were consistently the most vegetationally simple sites.

Figures 9-21 and 9-22 illustrate the reduced species diversity, elimination of common and rare species found in reference areas and replacement by sparse cover of redtop bentgrass and moss, the reduction in biomass and productivity as indexed by cover, and the vertical simplification as reduction in cover in the herbaceous and shrub layers.

9.5.5 Evaluation of Causal Factors

Evidence of Hazardous Substance Causality

The results of the field vegetation studies and the relationships between soil chemistry, plant growth performance, and field vegetation structure and composition are consistent with metals toxicity as the cause of the adverse effects to vegetation. Evidence that hazardous substance concentrations in floodplain assessment soils cause injury to vegetation includes the following:

- **The assessment soils are contaminated with hazardous substances.**

Assessment area floodplain soils contain elevated concentrations of cadmium, lead, and zinc and other hazardous substances. Data presented in Tables 2-9 through 2-11 and 2-14 through 2-17 (Chapter 2), Table 9-3, and Figure 9-6 confirm that concentrations in assessment soils are elevated and exceed concentrations in reference soils.

Figure 9-21. Herbaceous species composition by site. Sites are presented by cluster group. Herbaceous species that occurred at fewer than two sites are not shown. Triangles: cover less than 10% of the total vegetation cover at the site. Circles: cover 10% or more of the total vegetation cover at the site. Red: "low metals" soils; green: "medium-low metals" soils; brown: "medium-high metals" soils; blue: "high metals" soils.

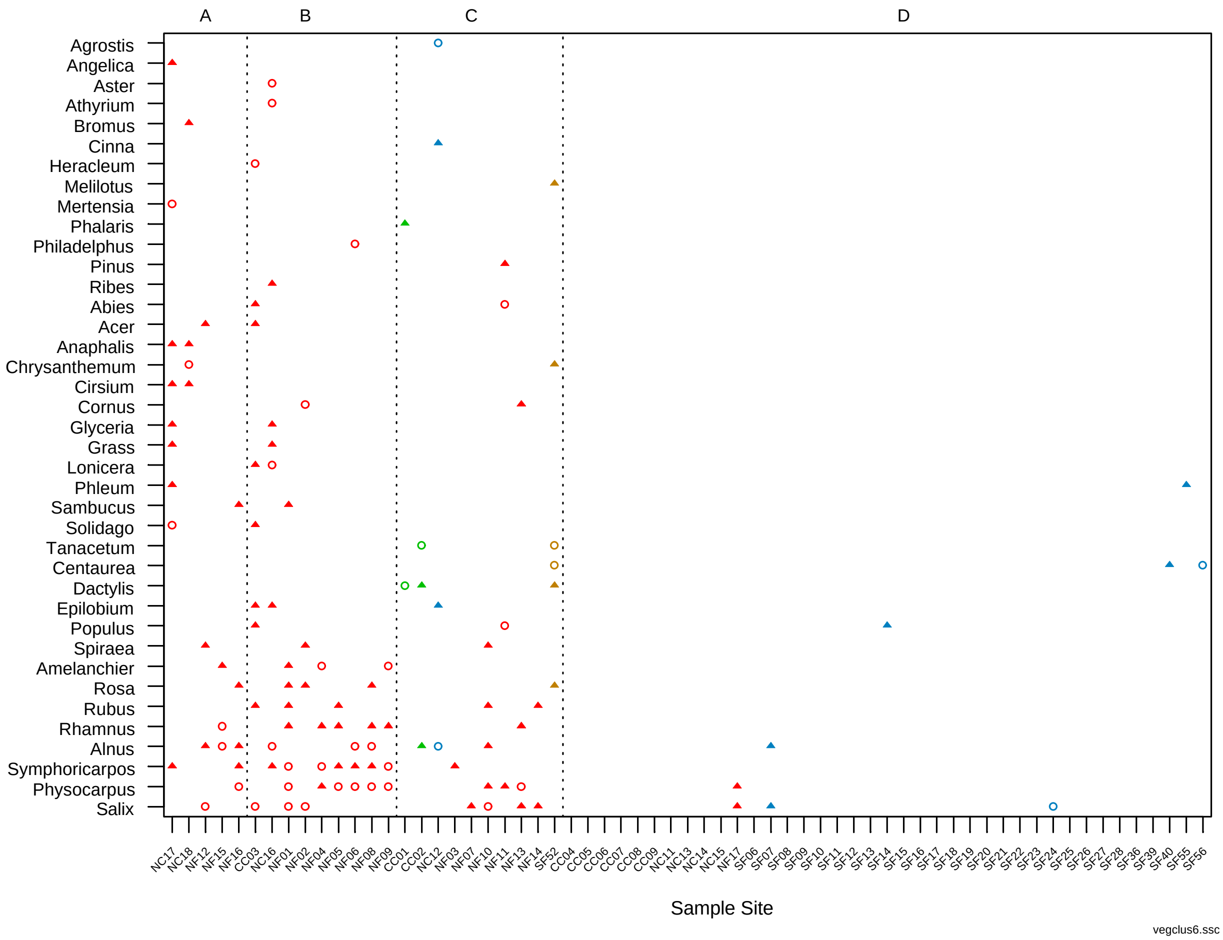

Figure 9-22. Shrub species composition by site. Sites are presented by cluster group. Shrub species that occurred at fewer than two sites are not shown. Triangles: cover less than 10% of the total vegetation cover at the site. Circles: cover 10% or more of the total vegetation cover at the site. Red: “low metals” soils; green: “medium-low metals” soils; brown: “medium-high metals” soils; blue: “high metals” soils.

▸ **Concentrations of hazardous substances in assessment soils exceed phytotoxic thresholds.**

The concentrations of hazardous substances measured in the assessment soils exceed phytotoxic thresholds described in the scientific literature and concentrations measured in other tailings-contaminated floodplain deposits that are vegetationally sparse or barren (Kabata-Pendias and Pendias, 1992; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000; Table 9-2). Maximum zinc concentrations in the assessment soils exceed toxic concentrations reported in the literature by three orders of magnitude, and mean zinc concentrations in Canyon Creek, Ninemile Creek, and South Fork Coeur d'Alene River assessment soils exceed phytotoxic concentrations by two orders of magnitude (Kabata-Pendias and Pendias, 1992). Concentrations of zinc in assessment soils are comparable to zinc concentrations determined to inhibit plant growth in Bunker Hill soils (Brown et al., 1998) (Table 9-14).

Table 9-14
Range of Mean Total Concentrations that Inhibited Plant Growth in Bunker Hill Revegetation Plots and Range of Mean Total Concentrations in Canyon Creek, Ninemile Creek, and South Fork Assessment Soils

	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
Phytotoxic Thresholds[a]	3-8	100-400	70-400
Phytotoxic I-90 Plots[b]	7-22	1,500-4,900	5,500-14,700
Phytotoxic Hillside Plots[b]	21-44	700-2,000	1,000-3,000
Assessment Soils	9-40	12,400-27,300	2,580-5,550

a. Source: Alloway, 1990b.
b. Source: Brown et al., 1998.

▸ **Plant growth performance in assessment soils was reduced significantly relative to plant growth performance in reference soils in controlled laboratory tests.**

Growth in upper basin assessment soils of all species tested (lettuce, wheat, alfalfa, and poplar) and most endpoints (root length, shoot length and mass, and branch length) was reduced relative to growth in reference soils. In the laboratory, soil moisture, temperature, and photosynthetically available radiation were maintained at favorable levels for plant growth. The short exposure period (two weeks from time of planting to harvest) precluded the need to add nutrients, since stored reserves in the seed should be sufficient to support the seedlings at least during initial growth. Removing factors other than soil chemistry that might affect plant growth allowed a test of the phytotoxicity of substances in the soil that affect early seedling growth potential. The results confirm that phytotoxicity is manifest early in the life stages of plants, even in short duration exposures.

- **Plant growth in laboratory phytotoxicity studies was negatively correlated with concentrations of hazardous substances in soils.**

Growth of all plant species tested was negatively correlated with concentrations of lead, and stem length of alfalfa, lettuce, and wheat, and stem mass of wheat were negatively correlated with other metals and arsenic. The exposure-response relationships provide evidence of a causal linkage between lead and other hazardous substance concentrations in soils and the observed injury to field vegetation. Growth responses were negatively correlated with nitrate, which is typically a limiting nutrient to plants and does not accumulate in soil. The negative correlations with nitrogen were more likely a consequence of reduced nutrient uptake in toxic soils than a cause of growth inhibition. The absence of consistent correlations between other soil factors and growth inhibition, and the observed phytotoxic response of growth inhibition, are consistent with metals toxicity as the cause of growth reduction. Nutrient deficiency, if it had been expressed during the short exposure time, typically causes increased root length and similar or slightly reduced root mass relative to plants grown in nutrient sufficient conditions. No factor other than metals toxicity adequately explains the consistent growth reduction response nor the increased growth reduction response with increased metals concentrations, across all species and endpoints.

- **Vegetation cover, species diversity, and structural complexity in the field were negatively correlated with concentrations of hazardous substances in soils.**

In upper basin sites, cover and species diversity in the herbaceous, shrub, and tree layers and number of structural habitat layers were significantly negatively correlated with hazardous substance concentrations. Percent bare ground, in contrast, was positively correlated with hazardous substance concentrations. Vegetation measures were also positively correlated with organic carbon and clay content, and negatively correlated with sand content. These attributes covary with the degree of contamination, but the existing concentrations of organic carbon, clay, and sand alone are not sufficient to explain the observed field vegetation responses. Multivariate relationships between soil chemistry and vegetation structural and compositional complexity were consistent with the univariate correlations. Increasing metals concentrations and increasing heterogeneity of metals concentrations were associated with increasing compositional and structural simplification of vegetation communities. Moreover, the field vegetation and hazardous substance correlations are consistent with the laboratory correlations between plant growth and hazardous substance concentrations.

In the lower Coeur d’Alene basin, relationships between hazardous substance concentrations and vegetation cover, structure, and compositional indices were less pronounced. A significant negative relationship between cover in the herbaceous layer and metals concentrations and a significant positive correlation between cover in the herbaceous layer and organic carbon were detected, but no other significant relationships were detected. Concentrations of cadmium, lead, and zinc in lower Coeur d'Alene soils, while still substantially elevated relative to those in reference soils and phytotoxic thresholds, are significantly lower than concentrations in upper basin assessment soils (Table 9-3). In addition, the lower Coeur d'Alene soils contain significantly greater organic carbon content and significantly greater percent clay (mean 6.53% organic carbon; 15.7% clay) than upper basin assessment soils (mean 1.6% organic carbon; 6.5% clay) (Mann- Whitney $p < 0.01$). Clay minerals and organic matter are among the most important soil components contributing to the sorption of metal cations (Kabata-Pendias and Pendias, 1992). Complexing of metals with organic ligands and sorption by clay minerals decreases their availability for plant uptake.

The greater organic carbon and clay content of the lower basin soils is typical of large, meandering broad valley floodplain soils. Organic inputs (e.g., leaves, woody debris, microbes, and processed organic matter) from upstream production and processing are transported by the river to the lower valley floodplain (Vannote et al., 1980; Gregory et al., 1991). Transport of allochthonous material, including coarse, fine, and dissolved organic matter, from upstream reaches and tributaries is a major bioenergetic input to large rivers (Vannote, 1980). At high flow in the lower basin, the river spreads across the broad valley floor, dissipating much of the energy of the current, and suspended sediments and organic matter are deposited on the terrace and floodplain surfaces. The higher clay content of the lower basin sediments reflects the hydraulic sorting and transport of the finer materials farther downstream, and in large rivers, a large portion of the fine sediments is composed of mineral sediments that became coated with organics while in the stream (Gregory et al., 1991). Therefore, the higher clay and organic content of the lower basin soils is expected, based on river continuum and energetics processes. These materials are derived from the North Fork Coeur d'Alene River basin, the South Fork, and from smaller tributaries to the mainstem Coeur d'Alene River in the lateral lakes area. Dilution of the South Fork sediment inputs by North Fork and tributary sediment and organic matter inputs has attenuated the phytotoxicity of hazardous substance contamination in much of the lower basin.

The comparisons between the assessment and reference sites show statistically and ecologically significant differences between concentrations of hazardous substances in soils, and between vegetation community structure and composition. The structurally complex and dense vegetation expected in the riparian zones of the South Fork Coeur d'Alene River and Canyon and Ninemile creeks has largely been eliminated along the assessment reaches. Riparian communities downstream of milling sites in the upper basin are sparse, floristically poor, and structurally simple. Large areas of the floodplain are barren or covered by scattered grasses and mosses.

Other Potential Causal Factors

Factors other than toxicity of floodplain soils by metals in tailings and mixed tailings and alluvium could cause or contribute to the measured effects on riparian vegetation. Contributing stressors include early logging and clearing of the floodplains; channelization, road building, construction, and industry in the urban corridor; accelerated channel meandering with the increased sediment load of tailings; and lack of nutrients, organic matter, and water-holding capacity in floodplain tailings deposits. It is reasonable to recognize that the riparian zones of the South Fork Coeur d'Alene River and its tributaries are subject to numerous anthropogenic stressors in addition to hazardous substances in floodplain tailings materials, and that disturbances that occurred in the past may have lasting effects on the current condition of the riparian ecosystem.

Photographs of Burke and Wallace taken in the late 1880s and 1890s show that the riparian zones had already been cleared and cedar swamps drained during development of the towns (Magnuson, 1968). Milling began in the basin in 1886 at the Bunker Hill mill. From that time until 1968, discharge to streams and floodplains was the predominant tailings disposal method (Long, 1998; Fahey, 1990). The volume of tailings discharged overwhelmed the transport capacity of the rivers in the upper basin. Aggradation of the channel and the floodplain caused rapid meandering of the South Fork Coeur d'Alene River across the floodplain (Ioannou, 1979). Impoundments in lower Canyon Creek and on the South Fork Coeur d'Alene River near Osburn and Smelterville in the early part of this century buried the native floodplain under many feet of tailings.

A combination of physical and chemical disturbances most likely contributed to the original degradation of the natural functioning of the riparian ecosystem along the South Fork Coeur d'Alene River, Canyon Creek, Ninemile Creek, and other tributaries of the upper basin. The reference reaches were also subjected to substantial historical physical disturbance. Between 1880 and 1965 over 400 sawmills operated in the Coeur d'Alene River basin (Idaho Panhandle National Forests, 1998). Streams, rivers, and lakes were used to convey logs to sawmills. Splash dams and log chutes were constructed in the Little North Fork and other tributaries of the North Fork Coeur d'Alene River (Idaho Panhandle National Forests, 1998). Splash dams were temporary structures built to raise the water level and increase the energy of smaller streams to carry logs down to larger rivers. Logs, and a large volume of sediment that eroded from logged hillsides adjacent to the stream, were stored behind the dam. When the dam was breached, the accumulated logs, water, and sediment were discharged downstream to the next dam, where the process was repeated (Rabe and Flaherty, 1974). The flood and logs scoured the downstream riparian zones, and the accumulated sediments were moved downstream. Since the Little North Fork served as a reference site for riparian vegetation, the historical effects of physical disturbances related to logging, erosion, and floodplain and channel alterations are accounted for in the reference condition.

After the construction of tailings impoundments in the South Fork Coeur d'Alene River basin in 1968, sediment loading decreased substantially. Expected pioneer communities that naturally develop on alluvial deposits following flooding have not established in the upper basin, despite the presence of a seed source from the South Fork Coeur d'Alene River headwaters and freshly exposed mineral soils to which early successional riparian species are adapted (Hansen et al., 1990; Gregory et al., 1991). The floodplains of the South Fork Coeur d'Alene River and certain tributaries have remained substantially barren, and the functions of the riparian zone are not recovering naturally. Where revegetation projects in the upper basin floodplain have been initiated, long-term survival of plants has been low. Various revegetation projects in the upper basin have cited nutrient deficiency, water stress, and metals toxicity as contributors to the poor survival (Section 9.3.2).

In a naturally functioning riparian floodplain, nutrient availability is often high as a result of high clay and organic content in soils, and because of continual replenishment during flooding (Mitsch and Gosselink, 1986). Mineral nitrogen, which is often the most limiting nutrient in natural ecosystems, is largely derived from microbial decomposition of soil organic matter. Since tailings lack organic matter and cause toxicity to plants that would produce the organic matter in soils, the current toxic floodplain materials may lack sufficient total nitrogen to support long term plant growth (Claassen and Hogan, 1998). Although nitrate concentrations in upper basin assessment soils were significantly greater than in reference soils (Section 9.5.1), the concentrations represent relatively small amounts of plant-available nitrogen. Since nitrate is highly mobile and rapidly sequestered by plants or leached from natural systems, its greater accumulation in the assessment soils most likely reflects the lack of vegetative uptake.

Phosphorus can also be abundant in typical floodplain soils (Mitsch and Gosselink, 1986). In mature soils, phosphorus in the upper soil profile is predominantly held in organic forms, and plant growth may depend largely on the release of phosphorus from soil organic matter (Schlesinger, 1997). A comparison of phosphorus concentrations in assessment and reference soils was not made (phosphorus data were rejected as a result of poor matrix spike results). However, it is not unlikely that concentrations differ between assessment and reference area soils because mine wastes are often phosphorus-deficient, and the current toxic floodplain materials may be phosphorous deficient.

Revegetation studies conducted in the mid-1970s showed that irrigation was necessary to ensure survival of seeded grasses on Smelterville Flats (Section 9.3.2). In a naturally functioning floodplain, the duration and frequency of flooding or drought and the depth to the water table control riparian vegetation community types, and the existing riparian vegetation canopy density influences the heat inputs to the stream and soil surface (Hansen et al., 1990; Gregory et al., 1991). Pioneer communities develop on recent alluvial deposits near the river, where water is abundant. More mature late successional communities are found on the higher stream terraces where flooding disturbance is less frequent and depth to the water table is greater (Hansen et al., 1990; Gregory et al., 1991). Historical elimination of vegetation changed the microclimate of the riparian zone by reducing shading and water retention, and increasing evaporation. The absence of organic matter and root structure in the existing floodplain materials has probably reduced infiltration and water-holding capacity of the floodplain materials, and aggradation of materials in the floodplain may have changed the depth to the water table in parts of the valley. The current microclimate of the upper basin riparian zone is probably warmer and drier than a natural floodplain. Therefore, in some parts of the floodplain, water limitations could conceivably contribute to plant growth limitation. However, the change in microclimate has resulted from toxic floodplain tailings that eliminated vegetation and have prevented reestablishment of vegetation.

The field vegetation responses were positively correlated with percent organic carbon and clay and negatively correlated with percent sand. Since tailings are sandy and silty, and have no organic matter, and since tailings deposits are phytotoxic and organic matter is not being added to the soil as it would in a functional vegetation community, the observed correlations are not unexpected. The majority of the assessment soils were classified as sandy loams or loamy sands, based on the percentage of sand, silt, and clay (Brady and Weil, 1996). These are soil textural classes that would be expected to support vegetation. There is no reason to expect that based on texture alone, the soils would inhibit plant growth.

Riparian soils, particularly soils on which early successional riparian communities develop, are freshly deposited mineral sediments that may be low in organic matter. There is no reason to expect that the low organic carbon content is a cause of the plant growth inhibition at the assessment sites, but rather, it is a result of the toxic effects of the hazardous substances in the soils and resulting devegetation.

Urbanization and channelization undoubtedly have had effects on the natural flooding regime, nutrient inputs, and nutrient cycling. Construction in the floodplain has reduced the area of floodplain that could be occupied by natural riparian habitat. However, throughout the world, riparian zones of rivers bordered by towns, cities, interstates, and railroads do not exhibit the characteristics of the riparian zone of the South Fork Coeur d'Alene River. Moreover, sampling was conducted only in nonurban areas of the floodplain.

There are most likely a combination of factors that contributed to the original elimination of vegetation in the floodplains during the late 1800s and early 1900s. However, the only factor that consistently explains the toxicity of the soils to plants, and the continued preclusion of natural recolonization of the floodplains, is hazardous substance concentrations in the soils. The most significant and substantial differences between reference soils and assessment soils are the concentrations of hazardous substances in assessment soils relative to reference soils and the phytotoxicity of the assessment soils. The soil chemistry data, the vegetation community measurements, the phytotoxicity test results, and the negative correlations between hazardous substance concentrations and plant growth performance in the laboratory, vegetative cover, species richness, and structural complexity in the field, as well as previous revegetation studies conducted in the basin, consistently support the conclusion that elevated concentrations of hazardous substances in floodplain soils of the upper Coeur d'Alene River basin currently cause injury to vegetation communities. While historical activities have caused changes in the ecological functioning of the riparian ecosystem, the existing concentrations of hazardous substances in floodplain soils continue to cause phytotoxicity and to inhibit vegetation community development.

Conclusions

The injury assessment studies were designed as a triad of complementary studies (Figure 9-23). The soil chemistry analysis confirmed that hazardous substance concentrations are elevated in assessment soils compared to reference soils and that concentrations exceed published phytotoxicity thresholds. The laboratory phytotoxicity tests using field collected soils confirmed that South Fork Coeur d'Alene River basin soils containing elevated concentrations of hazardous substances are toxic to plants, and that the plant growth inhibition is positively correlated with increasing metals concentrations. The field vegetation data collected at the sites where soil samples were collected confirmed that as hazardous substance concentrations increase, the cover of vegetation decreases, the species diversity decreases, the structural complexity of vegetation communities decrease, and cover of bare ground increases. The field exposure-response relationships are consistent with the laboratory phytotoxicity exposure-response relationships, and both are consistent with published data on effects of metals in mine wastes on plant growth and vegetation community responses.

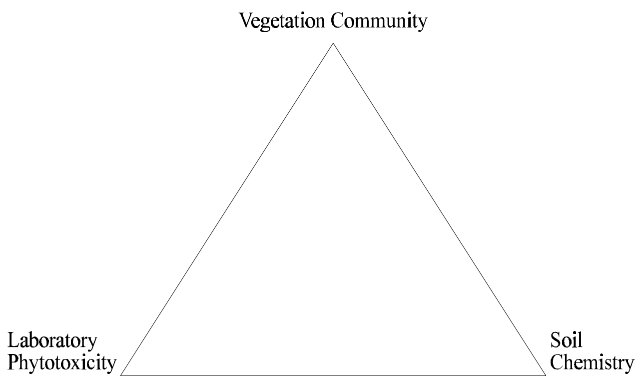

Figure 9-23. Injury determination "triad" approach.

Metals toxicity is the only consistent explanation of the results observed in the field and laboratory study components. Nutrient deficiency does not explain the growth inhibition measured in the laboratory phytotoxicity tests; water limitation does not explain the growth inhibition measured in laboratory phytotoxicity tests; physical disturbance does not explain the growth inhibition measured in laboratory phytotoxicity tests; urbanization, channelization, and physical disturbance do not explain the growth inhibition measured in laboratory phytotoxicity tests; and historical disturbances associated with the floodplain do not explain the growth inhibition measured in laboratory phytotoxicity tests. Field vegetation responds to a more complex set of environmental stressors, but the consistency of the correlations between field vegetation cover, species diversity, and structural complexity and metals concentrations in soils is evidence that hazardous substances are a strong determinant of the existing vegetation.

9.6 INJURY DETERMINATION EVALUATION

Historical information and the results of the injury determination studies confirm that riparian resources of the South Fork Coeur d'Alene River basin are injured. In summary, information considered during the injury assessment confirms that:

- Surface water and sediments containing elevated concentrations of hazardous substances serve as transport and exposure pathways of hazardous substances to floodplain soils of the Coeur d'Alene River basin.

- Floodplain soils and sediments contain elevated concentrations of hazardous substances, and concentrations are sufficient to expose riparian vegetation to hazardous substances.

- Riparian resources of Canyon Creek, Ninemile Creek, the South Fork Coeur d'Alene River, and the lower Coeur d'Alene River, including soils and vegetation, are exposed to elevated concentrations of cadmium, lead, and zinc.

- Hazardous substances in floodplain soils of the upper basin are sufficient to cause:

    - a phytotoxic response, specifically, retardation of plant growth [43 CFR § 11.62 (e)(10)]

    - adverse changes in viability, specifically, reductions in vegetation cover, and simplification of community structure and composition [43 CFR § 11.62 (f)(1)(i)].

A causal link between concentrations of hazardous substances in upper basin floodplain soils and adverse effects on riparian vegetation has been established. Similar responses have been observed at other mine sites where floodplains are contaminated with mine wastes, and no other potential factor explains the responses measured in both the laboratory tests and the field vegetation studies.

In addition, the sources and pathways of metals to floodplain soils of Pine and Moon creeks are similar to the sources and pathways of metals to floodplain soils of Canyon and Ninemile creeks and the South Fork Coeur d'Alene River (Chapters 2 and 3), and the concentrations of hazardous substances are similar to concentrations determined to be phytotoxic on Canyon and Ninemile creeks and the South Fork Coeur d'Alene River. Therefore, barren and sparsely vegetated areas of Pine and Moon Creek riparian zones are inferred to be injured as a result of phytotoxic concentrations of hazardous substances in the floodplain soils.

9.6.1 Pathway Determination

The purpose of the pathway determination is to identify the route or media by which hazardous substances have been transported from sources to riparian resources of the Coeur d'Alene River basin [43 CFR 11.63]. Information used in the pathway determination for riparian resources included:

- ***Hazardous substance sources.*** Information presented in the Chapter 2 confirms that historical sources discharged tailings to the basin, and that hazardous substances have come to be located in bed, bank, and floodplain sediments (and floodplain soils) throughout the basin. These contaminated floodplain, bed, and bank sediments are remobilized and re-released, and serve as ongoing sources of contamination (Figure 9-24).

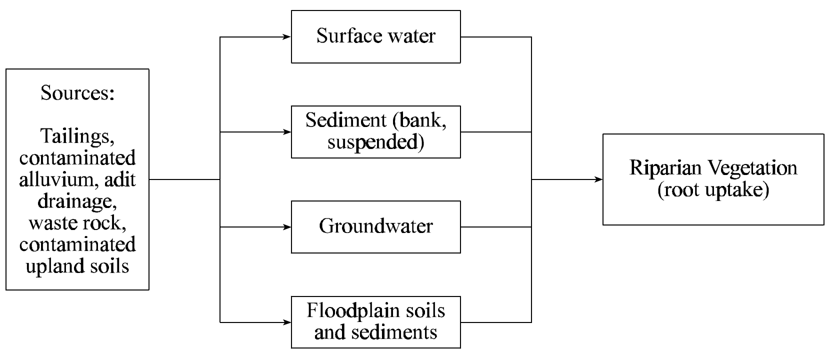

Figure 9-24. Hazardous substance transport and exposure pathways to riparian resources (transport via water/sediment; exposure via soils, vegetation).

- ***Transport pathways.*** Hazardous substances are transported by surface water as dissolved and suspended sediments and deposited on floodplain surfaces (Chapters 3, 4, and 5 — Transport and Exposure Pathways, Surface Water Resources, and Sediment Resources).

- ***Exposure pathways.*** Floodplains have been and continue to be exposed to deposition of hazardous substances transported by surface water. Riparian vegetation is exposed to hazardous substances by root exposure to and uptake from contaminated soils and sediments.

Pathways were determined by demonstrating that sufficient concentrations exist in surface water and floodplain soils and sediments to expose riparian resources of the Coeur d'Alene River basin to hazardous substances. Exposure of vegetation was confirmed by negative correlations between concentrations of hazardous substances soils and the growth response of plants.

Floodplain soils are exposed to hazardous substances historically deposited (such that the floodplains now serve as sources) and to hazardous substances that continue to be transported by surface water. Riparian vegetation is exposed to hazardous substances by root uptake of metals in soil water. The total concentrations measured in soils and sediments (Table 9-3) are not all available for uptake. Some of the metals in soils are bound by organics, occluded in iron and manganese oxides, held in metal carbonates, phosphates, or sulfides, or structurally bound in silicates. The fraction of metal cations that are in the soil solution or exchangeable pools is the most readily available to plants. However, the consistency of negative correlations between total lead concentrations and plant growth (Table 9-6), and between total metal concentrations and field vegetation measures (Table 9-12) is supporting evidence of the exposure pathway of plants to hazardous substances in soils and of the bioavailability of hazardous substances to plants. As concentrations of hazardous substances in soils increase, plant growth is inhibited, vegetation cover, species richness, and structural heterogeneity in the field decrease, and bare ground increases. Data presented in this chapter and Chapter 2 confirm that concentrations in floodplain soils are sufficient for floodplain soils to serve as an exposure pathway to riparian resources [43 CFR 11.63 (a)(2)].

In summary:

- ***Sufficient concentrations of hazardous substance exist in pathway resources to transport hazardous substances from multiple sources to riparian resources.*** The source of hazardous substances to riparian resources is the historical and ongoing release of hazardous substances from mining related operations. Hazardous substances are transported in surface water resources, mixed with suspended and bed sediments, and deposited on floodplain soils. Hazardous substances that have come to be located in floodplain, bed, and bank deposits are ongoing sources and transport pathways of hazardous substances to downgradient riparian resources. Concentrations of hazardous substances in floodplain soils and sediments of South Fork and lower Coeur d'Alene River basin are significantly greater than baseline (Chapter 10), and floodplain soils and sediment containing elevated concentrations of hazardous substances serve as an exposure pathway to riparian vegetation.

  Hazardous substance concentrations in surface water [43 CFR 11.63 (b)] and geologic resources [43 CFR 11.63 (e)] are sufficient to expose floodplain soils and sediments and riparian vegetation to hazardous substances.

9.6.2 Injury Determination: Phytotoxic Response

Soils are injured if concentrations are sufficient to cause a phytotoxic response such as retardation of plant growth [43 CFR § 11.62 (e)(10)]. Since the DOI regulations and the ASTM test procedure used do not specify a threshold or statistic to be used in the determination of phytotoxicity, the phytotoxicity was defined as a significant reduction in growth relative to reference.

Laboratory tests confirm that soils from the South Fork, Canyon Creek, and Ninemile Creek assessment areas cause significant reductions of seedling shoot and root growth relative to growth in reference soils. Under controlled conditions, including conditions of ample light, water, and space, and in the absence of physical disturbances, plant growth of multiple species was inhibited in assessment soils relative to reference soils. Alfalfa, lettuce, and wheat each exhibited reduced shoot length and total length, and wheat exhibited reduced shoot mass and total mass. Poplar exhibited reduced branch length, leaf mass, and root length. The controlled conditions removed stressors other than nutrient limitation that could contribute to growth limitations in the field. The short exposure period reduced the influence that nutrient limitation could have had, since reserves in the seed (or poplar cutting) are most likely sufficient to sustain the plant through germination and initial root elongation stages. Moreover, nutrient limitation typically causes root elongation rather than the root stunting measured.

Correlation analyses indicated that for alfalfa, lettuce, and wheat, root length, stem mass, and stem length, total mass, and total length, and for lettuce, root mass also, were significantly negatively correlated with concentrations of lead. Stem length for all three species was significantly negatively correlated with arsenic, cadmium, copper, iron, manganese (except lettuce), and zinc in addition to lead. Correlations with nitrate were also negative. No other consistent correlations were observed. For poplar, branch growth, leaves added, and leaf mass were significantly negatively correlated with lead. Branch growth and root growth were negatively correlated with nitrate and positively correlated with organic C. No other consistent correlations were observed. These results are consistent with the scientific literature on metals toxicity to plants (e.g., Kabata-Pendias and Pendias, 1992; Alloway, 1990b), with scientific literature on plant responses to metals in mine wastes (e.g., Kapustka et al., 1995; LeJeune et al., 1996; Rader et al., 1997), and with laboratory studies previously conducted with Coeur d'Alene River basin floodplain soils (Keely, 1979; Krawczyk et al., 1988).

Assessment of floodplain soil pH confirmed that most assessment soils have pH greater than 4. One sample from Canyon Creek had pH less than 4 [43 CFR § 11.62 (e)(2)].

The results of the laboratory plant growth test confirm that plant growth in upper basin assessment floodplain soils containing elevated concentrations of hazardous substances is inhibited relative to plant growth in reference soils, and that the upper basin assessment soils are injured [43 CFR § 11.62 (e)(10)]. The concentrations of hazardous substances in the assessment soils are sufficient to cause injury to riparian vegetation exposed to the upper basin assessment soils [43 CFR 11.62 (e)(11)]. This injury is discussed further as an adverse change in viability (Section 9.6.3).

9.6.3 Injury Determination: Adverse Changes in Viability

An injury to a biological resource has occurred if the release of a hazardous substance is sufficient to cause one or more of the following adverse changes in viability: death, disease, . . ., physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)(i)]. Adverse changes in viability of biological resources were demonstrated using biological responses that meet the acceptance criteria at [43 CFR § 11.62 (f)(2)].

- The biological response is often the result of exposure to hazardous substances [43 CFR § 11.62 (f)(2)(i)].

- Exposure to hazardous substances is known to cause this biological response in free-ranging organisms [43 CFR § 11.62 (f)(2)(ii)].

- Exposure to hazardous substances is known to cause this biological response in controlled experiments [43 CFR § 11.62 (f)(2)(iii)].

- The biological response measurement is practical to perform and produces scientifically valid results [43 CFR § 11.62 (f)(2)(iv)].

The results of the laboratory growth tests confirmed that plant growth is reduced in soils containing hazardous substances relative to plant growth in reference soils, in a controlled laboratory environment [43 CFR § 11.62 (e)(10)], and the field sampling confirmed that vegetation cover, species richness, and structural complexity are reduced in the upper basin assessment area relative to the reference areas. The community level changes observed are caused by death and physical deformation at the level of the individual plant, where deformations include physiological changes resulting in reduced growth. Reduced growth leads to a loss in competitiveness and viability. Death and physiological deformations are expressed at the community level in the upper Coeur d'Alene River basin as elimination of vegetation or as changes in the composition or structure of vegetation communities.

Results of the field vegetation studies confirmed that upper basin assessment sites are significantly more barren than reference sites, and the reduction in vegetation cover is apparent in multiple vertical layers. Cover of vegetation in the herbaceous, shrub, tree, and litter layers is significantly reduced at upper basin assessment sites relative to reference sites. Species richness at upper basin assessment sites is significantly reduced relative to reference sites, and where vegetation is present on assessment sites, it is strongly dominated by a single metals-tolerant grass species (predominantly red top bentgrass). Rare species, or species that occur infrequently and comprise a minority of the total cover but contribute greatly to the total species richness at reference sites, were virtually absent at upper basin assessment sites. The structural complexity of vegetation communities at upper basin assessment sites is significantly reduced relative to reference sites, and thus the quality and quantity of habitat provided by riparian vegetation in the upper basin are significantly reduced relative to reference areas.

Correlation analyses showed a consistent negative correlation between vegetation complexity measures, including cover in the herbaceous, shrub, and tree layers; number of species in each layer; number of layers within a 10 m radius; and concentrations of hazardous substances. Percent bare ground was positively correlated with concentrations of hazardous substances.

In summary, the plant and vegetation responses measured as part of this injury assessment meet the four acceptance criteria at 43 CFR § 11.62 (f)(2):

- Growth reduction of individual plants, reduction in vegetation cover and species richness, and simplification of vegetation community structure are often the result of exposure to hazardous substances and are known to be caused by exposure to elevated concentrations of metals in soils (Chaney, 1993; Pahlsson, 1989; Kabata-Pendias and Pendias, 1992; Kapustka et al., 1995). Growth reductions are the manifestation at the whole-plant level of physiological malfunctions such as inhibition of photosynthesis, water transport, nutrient uptake, carbohydrate translocation, transpiration, and enzyme synthesis or activity induced by elevated concentrations of trace elements (Carlson and Bazzaz, 1977; Lamoreaux and Chaney, 1977; Clijsters and Van Assche, 1985 Pahlsson, 1989; Tyler et al., 1989; Vasquez et al., 1989; Alloway, 1990a; Davies, 1990; Kiekens, 1990). Reductions in cover, species richness, and vegetation community structure are manifestations at the community level of the reduction in viability at the individual plant level.

- Exposure to hazardous substances is known to cause shoot and root growth reduction and reduced plant survival in controlled experiments [43 CFR § 11.62 (f)(2)(iii)] (Tyler et al., 1989; Kapustka et al., 1995), and exposure to hazardous substances is known to cause reduced cover, species richness, and structural complexity in wild vegetation [43 CFR § 11.62 (f)(2)(ii)] (Johnson and Eaton, 1980; LeJeune et al., 1996; Rader et al., 1997; Stoughton and Marcus, 2000).

- Measurements of reduced growth and survival in laboratory tests and measurements of reduced vegetation cover and changes in community composition and structure in the field are practical to perform and produce scientifically valid results (U.S. DOI, 1987; ASTM, 1994; Kapustka, 1997).

These responses meet the four acceptance criteria at 43 CFR § 11.62 (f)(2) and therefore, confirm that riparian resources of the upper Coeur d’Alene River basin are injured.

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