Introduction and overview of a study dealing with the role of salt-affected soils in primary succession on the Tanana River floodplain, interior Alaska

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This paper provides an overview of the environmental setting, rationale, and organization of a multidisciplinary research program designed to examine the role of salt-affected soils in primary succession on the Tanana River floodplain of interior Alaska. The papers included in this series report results of studies designed to examine the controls of salt-affected soil formation and vegetation development and their interaction in this fluvial environment. The association of pedogenic salts and forests is largely restricted to northern latitudes where both low precipitation and moderate potential evapotranspiration occur simultaneously. In contrast with upland secondary-successional sites, where fire is the principal determinant of forest type distribution and successional change, ecosystem processes on the floodplain are determined by the fluvial nature of the environment. Consequently, the research presented an opportunity to evaluate some of the markedly contrasting controls of development that exist between forests in the two topographic locations. This study makes a substantial contribution to our understanding of how soil and vegetation interact on interior Alaskan floodplains to give rise to productive, commercially valuable forests.


Cette publication donne une vue d’ensemble des conditions environnementales, du rationnel et de l’organisation d’un programme de recherche multidisciplinaire élaboré afin d’examiner le rôle des sols affectés par le sel dans la succession primaire de la plaine de débordement de la rivière Tanana de l’intérieur de l’Alaska. Les publications incluses dans cette série rapportent les résultats d’études effectuées pour examiner ce qui contrôle la formation du sol affecté par le sel et le développement de la végétation et leur interaction dans cet environnement fluvial. L’association de sels pédogéniques et des forêts est largement restreinte aux latitudes très nordiques où à la fois une faible précipitation et une évapotranspiration potentielle modérée s’observent simultanément. En opposition avec les stations des stades successionnels secondaires des hauteurs terres où le feu est le déterminant principal du type de distribution forestière et du changement successional, les processus des écosystèmes sur la plaine de débordement sont déterminés par la nature fluviale de l’environnement. Conséquemment, le programme de recherche a présenté une opportunité d’évaluer certains des contrôles fortement contrastants du développement qui existent entre les différentes forêts dans deux situations topographiques. Cette étude apporte une contribution substantielle à notre connaissance sur l’interaction du sol et de la végétation des plaines de débordement de l’intérieur de l’Alaska pour donner naissance à des forêts productives et de valeur commerciale.

Introduction

The river floodplains of interior Alaska are the sites of some of the most productive forests in the region. In the future, the relatively fast growing stands of balsam poplar (Populus balsamifera L.) and white spruce (Picea glauca (Moench) Voss) undoubtedly will experience increased utilization by the forest industry. Wise management of these forests requires a thorough understanding of ecological controls that act on these ecosystems throughout their successional history.

Ecological research has been carried out on the Tanana River floodplain for the past 20 years. This work has generally defined the course of forest succession and selected changes in state and function of these ecosystems (Van Cleve et al. 1971, 1980, 1986; Van Cleve and Viereck 1972, 1981; Walker et al. 1986; Walker and Chapin 1986). Information collected over the years includes estimates of species composition and species life history characteristics, physiological aspects of seedling development, standing crops of biomass and nutrient elements in various ecosystem compartments, and element flux.

Early in the 1980s research attention shifted to the earliest stages of primary succession on recently deposited alluvium, and specifically to the effects of salt-affected soils in influencing this succession. To explore this topic, an intensive, multidisciplinary study (The role of salt-affected soils in primary succession on the Tanana River floodplain of interior Alaska) was undertaken in 1985.

This paper provides an overview of the physiographic location in which the research was conducted, the rationale for conducting the work, and the objectives and structure of the research program.

Physiography

The physiographic setting for this unique environment is illustrated in Fig. 1. Interior Alaska is bounded on the south by the Alaska Range and on the north by the Brooks Range. The principal river systems draining interior Alaska are the Yukon and the Tanana.
The Alaska Range is glacially sculptured and trends in an arc 1000 km from the Canadian border to the Aleutian Range. It is composed of a core of Precambrian or lower Paleozoic schist and gneiss (Péwé and Rege 1983). The higher mountains are supported by granitic intrusions of Mesozoic age. Sedimentary and volcanic rocks of Paleozoic and Mesozoic age are encountered on the flanks of the range. Foothills and adjoining lowlands contain weakly consolidated, coal-bearing conglomerate, sandstone, and claystone of Tertiary age (Péwé and Rege 1983). At least four Quaternary glaciations occurred in the area of the central Alaska Range. The Alaska Range contains numerous peaks over 3000 m in elevation and culminates in Mount McKinley at 6195 m. This mountain wall is an effective barrier to coastal air masses, except for Pacific monsoonal systems that approach from the southwest. In general the mountain barrier reinforces the highly continental climate of interior Alaska.

The southern portion of the Yukon–Tanana uplands and adjacent Tanana River valley to the south, in the vicinity of Fairbanks, is the location for our research activities (Fig. 2). The Tanana River valley is a large structural basin with much of its bedrock floor below sea level (Péwé and Rege 1983). Fluvial and glaciofluvial sediments, largely from the rising Alaska Range, have accumulated in deposits 91–230 m thick south of Fairbanks. These deposits have pushed the Tanana River northward, near the Yukon–Tanana upland (Péwé and Rege 1983).

The Tanana River is 379 km long and heads in the Alaska Range to the southeast. It is primarily a glacial-fed river sustained by tributaries draining to the north from the Alaska Range and by nonglacial streams draining to the south from the Yukon–Tanana uplands (Collins 1990). Approximately 85% of the total annual discharge of the Tanana River originates from tributaries draining the Alaska Range, and the remaining 15% originates from streams draining from the Yukon–Tanana uplands (Collins 1990). Upstream, southeast of Fairbanks, the river becomes strongly braided. Downstream from Fairbanks, the river meanders across its floodplain (Fig. 3). Recent estimates (1974–1979) for the river at Fairbanks indicated that the average annual suspended-sediment load (silt to very fine sand) was $20.7 \times 10^6$ to $24.0 \times 10^6$ t, and the bedload (fine sand to coarse gravel) was $29.8 \times 10^4$ to $32.1 \times 10^4$ t (Péwé and Rege 1983). The mean annual discharge of the river during this period averaged 540 m$^3$/s (Péwé and Rege 1983). Flood periods tend to occur during spring snowmelt and during middle to late summer, when heavy rain or warm air quickly mount streams to flood capacity. The spring flood can be short-lived, caused by brief damming of the water by ice jams, or it can be of a longer duration when exceptionally heavy snowpacks are melted by warm spring weather. Destructive flooding on the Tanana River and tributary Chena River may occur at 50- to 100-year intervals.

Central Alaska has not been glaciated but small cirque glaciers occurred in local mountainous highlands. Glaciers from the Alaska Range approached to within 80 km of Fairbanks during extensive glacial expansions (Péwé and Rege 1983). Silt blown from the floodplain of the Tanana River was deposited as loess, blanketing ridges of the southern Yukon–Tanana upland in deposits from a few centimetres thick on summits to more than 45 m on middle and lower slopes (Figs. 2 and 3). Topography of the east-trending upland consists of rounded ridges 600–900 m in elevation, with higher peaks projecting to between 1500 and 1800 m (Péwé 1982). The current tree line is at approximately 750 m on hills in the local Fairbanks area (Viereck et al. 1983). The physiography and geology of the Fairbanks area include loess-covered bedrock hills, lower hillslopes, and creek-valley bottoms, organic-rich lowlands at the base of hills, and the Chena and Tanana river floodplains (Péwé 1982). Dating of peat accumulations in the Fairbanks area indicates that formation began approximately 3500 years ago (Collins 1990).

Permafrost is discontinuous in interior Alaska and is continuous north of the continental divide in the Brooks Range. Permafrost, or perennially frozen ground, is defined as a thickness of soil or other surficial deposit, including bedrock, that has been colder than 0°C for at least 2 years (Péwé 1982). Thickness of permafrost is greater than 600 m in northern areas but is only 1 to several metres thick near its southern limits (Brown and Kreig 1983). In the Fairbanks area permafrost thickness ranges from about 80 m on floodplains to in excess of 110 m in poorly drained lowlands (Péwé 1982).

In interior Alaska, distribution of permafrost and active layer thickness (portion of soil profile above permafrost that thaws and refreezes annually) are closely related to the topographic conditions slope, aspect, and drainage; thermal properties of the parent material; and vegetation (Dymess 1982; Dymess et al. 1988; Viereck et al. 1986). Depending on these conditions, the active layer thickness ranges from 0.5 to 6 m. In the Yukon–Tanana uplands, north aspects, valley bottoms, and poorly drained lower slopes are generally underlain by permafrost. Well-drained south aspects and sediments adjacent to and beneath active river channels are permafrost free. The presence of black spruce (Picea mariana (Mill.) B.S.P.), larch (Larix laricina (Du Roi) K. Koch), and bogs generally indicates the presence of permafrost. Occurrence of trembling aspen (Populus tremuloides Michx.) and white spruce generally indicates permafrost-free conditions. Paper birch (Betula papyrifera Marsh.) also develops on permafrost-free soil or where fire or clearing has resulted in lowering of the permafrost table (Brown and Kreig 1983).

Vegetation

Interior Alaskan forests are part of a circumpolar band of boreal forest. These forests are unique for their association with an environment characterized by drastic seasonal fluctuations in day length (more than 21 h on June 21 and less than 3 h on December 21, north of 64°N) and temperature (less than −40°C in January and over 25°C in July), a short growing season (100 days or less), consistently low soil temperatures, and the occurrence of permafrost (Van Cleve and Alexander 1981). Approximately 32%, or 42 800 000 ha, of the total 137 000 000 ha that make up interior Alaska is forested (Hutchinson 1967). The remainder is occupied by grassland, brushland, bogs, open water, and tundra, and rock outcrops, snow, and ice at high elevations. Forest land that is considered of commercial value totals about 9 600 000 ha.

Early work on the Tanana River floodplain forests generally defined the successional sequence and selected changes in state and function of these ecosystems (Van Cleve et al. 1971, 1980; Van Cleve and Viereck 1972, 1981). The general successional sequence consists of recognizable stages dominated by willows (Salix spp.), thimble alder (Alnus tenuifolia

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**Note:** The text provided seems to be a continuation of a larger scientific document, possibly from a journal, discussing the geography, climate, and vegetation of the interior of Alaska. The text is descriptive and likely includes detailed scientific observations and research findings.
Fig. 1. General physiographic setting of the study area (rectangle) in interior Alaska.
Fig. 2. Location of study site (Bonanza Creek Experimental Forest) on the Tanana River floodplain bounded on the north by the Yukon–Tanana uplands and on the south by the Alaska Range.
Fig. 3. Infrared aerial photograph of floodplain and adjacent uplands with vegetation types generally classified in the immediate vicinity of our study sites at Bonanza Creek Experimental Forest. For uplands: UWS, upland white spruce; UBS, upland black spruce; UD, upland deciduous (paper birch, trembling aspen); UDS, upland mixed deciduous–spruce; BU, recently burned uplands. For floodplain: BF, bare floodplain; FSP, floodplain shrubs, balsam poplar; TWS, terrace white spruce; TBS, terrace black spruce; TSS, terrace low shrub; BT, recently burned terrace.
economic development of interior Alaska these floodplain forests were heavily utilized for logs and lumber for construction and for fuel for powering river steamboats and heating homes. In the future, relatively fast growing balsam poplar and white spruce forests will undoubtedly receive considerable utilization by the forest industry. These sites may also provide interior Alaska’s best potential for future short-rotation energy forests. To best manage these forests it is essential that we have a thorough understanding of the ecological controls that act on these ecosystems throughout the entire successional sequence.

The river floodplains offer a unique opportunity to examine the course of forest ecosystem development and to gain insight into mechanisms that control this development. The various stages in primary and secondary succession reflect physical, chemical, and biological controls of ecosystem structure and function (Van Cleve and Viereck 1981 (Fig. 4). The interaction, or feedback relations, among the ecosystem controls and processes is displayed in the occurrence of the respective vegetation types and their growth rates and longevity. Each successional stage has a species combination that is in harmony with site quality.

Understanding the interplay of controls over successional change is an important step to developing sound forest management strategies. For example, short-circuiting succession by planting a late-successional species, such as white spruce, on an early-successional soil surface may result in markedly reduced growth rates because of N limitation, or periodic sedimentation may smother seedlings before they are established. Unless substantial amounts of fertilizer can be applied it may be necessary to take advantage of early-successional alder and its site-ameliorating additions of N to insure successful growth of spruce.

The association of pedogenic salts and forests is largely restricted to northern latitudes where both low precipitation and moderate potential evapotranspiration occur simultaneously. Most of the written information on this subject is in the Soviet literature (Kovalishin 1977; Lavrysheva 1970; Migunova 1976). However, this information is not sufficiently detailed to allow one to determine what factor(s) associated with the salts actually controls seed germination and plant growth or the availability of important soil nutrients. For example, although both soil N and P processes are known to be pH and salt dependent, until this study these relationships had not been examined in interior Alaska’s forest ecosystems.

Prior to this study, forest ecological research in interior Alaska largely concentrated on examining controls of structure and function in upland, secondary-successional forest ecosystems (Van Cleve and Viereck 1981; Van Cleve et al. 1983). This is the first study to focus solely on primary-successional, floodplain ecosystems. This research has presented the opportunity to evaluate some of the markedly contrasting controls that exist between forest in the two topographic locations.

Tree species composition in upland and floodplain forests differs in two important respects: trembling aspen, an impor-
tant upland species, is not encountered in primary-successional locations on the floodplain; balsam poplar, frequently encountered in the uplands, shows most extensive development on the floodplain. The mosaic of forest types and successional change in the uplands are largely determined by fire, whereas flooding determines the course of floodplain forest development. The principal contrast of floodplain sites with upland ecosystems in control of forest species composition, production, and nutrient cycling is the fluvial nature of the location and associated physical and chemical character of the floodplain soil. This study constitutes a substantial contribution to our understanding of how soils and vegetation interact on interior Alaskan floodplain sites to give rise to productive, commercially valuable forest stands.

To assess the role of salt-affected soils in the management of these forest ecosystems, three questions need to be answered: What is the effect of the salt-affected surface soils on germination, growth, and succession of native tree and shrub species? What are the factors controlling the formation of the salt-affected soils? What are the implications of formation of salt-affected soil for the long-term management of these forest ecosystems? These questions were examined in the research reported in this set of papers. In particular, we attempted to (i) isolate the critical factor(s) limiting vegetative growth in these salt-affected soils, (ii) identify the critical factor(s) controlling salt formation, and (iii) evaluate the effect of these factors on the long-term management of these forest ecosystems.

**Study site**

The study area lies within and adjacent to the Bonanza Creek Experimental Forest, about 20 km southwest of Fairbanks (Figs. 3 and 4). Here, on a number of islands and terraces adjacent to the river, all stages of forest succession can conveniently be observed (Figs. 3 and 4). Over the past 20 years we have established a number of permanent plots in stands of most stages of succession, where we have been recording vegetation changes, soils, and ecosystem processes, especially those related to nutrient cycling and biomass production. Some information from these studies has previously been published (Ganns 1977; Van Cleve and Viereck 1972, 1981; Van Cleve et al. 1971; Viereck 1970; Zasada and Gregory 1969; Walker et al. 1986; Walker and Chapin 1986; Kraszy et al. 1988).

Within each of two replicate sites, plots were established and samples taken from terraces representing early to late stages of forest succession. The youngest terraces were as follows: stage I prevegetated alluvial surfaces subjected to within-season sedimentation; the open willow stage II, which displayed extensive development of salt crust; and stage V, the poplar—alder stage (Fig. 4). Stage V was employed to test the vegetation canopy, forest floor, and transpiration controls of salt-affected soil formation. In addition, plots were established in mature white spruce (stage VIII).

Adjacent to the stages III and V controls, 30 × 50 m areas were cleared and maintained vegetation free for the duration of this study. These cleared sites were employed to test hypotheses concerning control of formation and demise of salt-affected soils.

Adjacent to the stage VIII control plots, clearcuts of approximately 8 ha were established and allowed to revegetate or were planted with seedlings. The objective of the latter work was to see what role salt formation played in reestablishing vegetation on secondary-successional seedbeds. This could have profound implications for the long-term management of these ecosystems. Four plant species were used in the experiments: (i) trembling aspen, an early-successional species not generally found on the floodplain; (ii) balsam poplar, an early-successional species generally found on the floodplain; (iii) thinleaf alder, an early-successional N-fixing species; and (iv) white spruce, a late-successional species.

**Central and working hypotheses**

**Central hypothesis I**

The presence and growth of tree and shrub species in early-successional locations on the Tanana River floodplain are controlled by the occurrence of high soil solution salt concentrations that form surface salt crusts on the early-successional mineral-soil seedbeds.

**Working hypothesis I-1**—The germination and early growth of tree and shrub species in these salt-affected soils are limited by high osmotic pressure of the soil solution.

**Working hypothesis I-2**—The germination and early growth of tree and shrub species in these salt-affected soils are limited by toxic concentrations of specific ions.

**Working hypothesis I-3**—The early growth of tree and shrub species in these salt-affected soils are limited by N availability.

**Working hypothesis I-4**—The early growth of tree and shrub species in these salt-affected soils are limited by P availability.

**Central hypothesis II**

The genesis and maintenance of surface salt crusts are controlled by the soil physical and chemical environments encountered on early-successional mineral-soil seedbeds.

**Working hypothesis II-1**—The formation of salt crusts is controlled by physical soil environmental parameters, including depth to water table, soil texture, capillary rise of solution from the water table, and rate of surface evaporation.

**Working hypothesis II-2**—The formation of salt crusts is controlled by the salt concentration of the groundwater.

**Central hypothesis III**

The disappearance of salt crusts and reduction in mineral soil salt concentration are controlled by forest succession, which mediates the changing soil physical, chemical, and biological environment.

**Working hypothesis III-1**—Evapotranspiration short-circuits capillary rise of the soil solution to the surface.

**Working hypothesis III-2**—Formation of a vegetation canopy and forest floor reduces wind movement over the mineral soil surface and hence reduces evaporation from this point and lowers the suction gradient, which is responsible for capillary rise of the soil solution.

**Working hypothesis III-3**—Acid leachates from decomposing forest floor organic matter result in dissolution of calcite (calcium carbonate) and gradual reduction in surface soil pH with advancing succession.

**Structure of research program**

The research was divided into five subprojects: soil physical and chemical environment, seed ecology, seedling growth and nutrition, salt crust genesis, and management effects and
Table 1. Contributions to the role of salt-affected soils in primary succession on the Tanana River floodplain of interior Alaska

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<td>Management effects and reforestation</td>
<td>J. Yarie</td>
<td>Effects of selected forest management practices on environmental parameters related to successional development on the Tanana River floodplain, interior Alaska</td>
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reforestation (Table 1). Each subproject had close association with other subprojects, through co-principal investigators, to insure maximum use of information, facilities, approaches, and ideas generated in hypothesis testing and to insure efficient use of personnel in conducting field and laboratory studies.

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