NORTHERN ALASKA RESEARCH STUDIES

Long-Term Gravel Vegetation Project, 1991 Annual Report

by

Jay D. McKendrick

Gwendo-Lyn Turner

Peter C. Scorup

Warren E. Fiscus

University of Alaska Fairbanks,

Alaska Agricultural and Forestry Experiment Station

Prepared for

BP Exploration (Alaska) Inc.

Long-Term Gravel Vegetation Project
1991 Annual Report

by
Jay D. McKendrick,
Gwendo-Lyn Turner,
Peter C. Scorup, and
Warren E. Fiscus

October 1993

Prepared by
University of Alaska Fairbanks
Alaska Agricultural and Forestry Experiment Station
533 East Fireweed
Palmer, Alaska 99645

Prepared for
BP Exploration (Alaska) Inc.
Environmental and Regulatory Affairs Department
P.O. Box 196612
Anchorage, Alaska 99519-6612

Executive Summary

Gravel fill is used for pads and roads on the coastal plain of Alaska's North Slope during exploration and production for oil and gas. Concern for losses of tundra habitat buried by gravel fill have been raised (Walker et al. 1987), with the loss of forage plants and useful habitat for animals being the primary foundation for those concerns. Such losses could be mitigated by establishing useful, functioning plant communities on these fills after they are no longer needed for oil and gas production. Therefore, in 1989, BP Exploration (Alaska) Inc. and the University of Alaska Fairbanks initiated a ten-year study of rehabilitating abandoned gravel fill sites used during exploration and production of oil and gas in arctic Alaska.

The project consists of three research areas (phases). The first is to test the effectiveness of modifying gravel fill to improve conditions for plant growth. The second is to identify indigenous plants in the Alaska Arctic that are adapted to colonizing gravel fill. The third phase is to monitor long-term aspect and plant community changes on gravel fill at exploratory and production sites. The first two phases are conducted mainly on the gravel fill at a former drilling site in the Prudhoe Bay Oil Field: BP Put River No. 1. The third phase involves studies of gravel fill at four locations in the National Petroleum Reserve in Alaska (NPRA) and at several locations along the Sagavanirktok River. Most results of the third phase are contained in a separate document prepared to describe details of studies on several gravel fills in NPRA. This report includes progress mainly for the first two phases of research, during the period 1989 through 1991.

At the time of this report, experiments had been underway on the BP Put River No. 1 gravel pad for two field seasons, under Phases I and II of this study. The major accomplishments include collecting seed during 1989, 1990, and 1991 for plantings in subsequent seasons. Respectively, these collections consisted of 42, 62, and 55 indigenous vascular arctic plants. In 1991 we also obtained seven species of arctic plants from the Tyumen region in Russia. Mixtures of 34 and 28 species were seeded on gravel modification plots in 1990 and 1991, respectively, from these collections. In addition, 63 rows of individual plant species have been planted in the botanical garden on the BP Put River No. 1 gravel pad. Under Phase III, the first re-examination of three abandoned drilling sites in NPRA occurred during July of 1991. A fourth NPRA site was surveyed during July, 1992, to complete the first of three scheduled evaluations to monitor long-term changes on abandoned gravel fill.

The most significant influence to date on the physical characteristics of gravel has been the addition of topsoil. It alters the bulk density and moisture content of the upper root zone and improves the production of plant cover. Tillage also reduces bulk density and seems to improve plant cover. Preliminary evidence indicates these treatments may also affect the uptake of certain minerals by plants. Snow fencing markedly altered the accumulation of snow, but it did not appear to affect plant canopy and basal cover values in the growing season subsequent to year of establishment.

Seed production was exceptionally abundant for many plant species of value to this project in the 1989

growing season. Just the opposite was true for the 1991 growing season, when few plants in the region produced mature seed. Examining temperature data revealed a fourfold difference in the cumulative, positive degree-hours (i.e., > 0°C or above freezing) at a coastal site between 1989 and 1991. The temperature patterns in the foothills between these two years were similar to those recorded on the coastal plain. Compared to locations near the coast, the air temperatures in the foothills consistently ranked higher, in terms of daily maximums and indicated a greater input of solar heat. However, among-year comparisons revealed the heating of air on the coastal plain in 1989 exceeded the heating of air in the foothills in 1991. The absolute diurnal variation was also greater in the foothills, and more hours of temperatures at or below freezing occurred during the growing season at the foothill site than on the coastal plain. In contrast, soil temperatures near the coast were consistently warmer during the growing season than in the foothills. Plant seed production was consistently greater in the foothills, suggesting that air temperatures, more than soil temperatures, were affecting the sexual reproductive performance of established vascular plant species.

One hundred twenty-five vascular plant species were found colonizing on gravel fill among ten locations examined on Alaska's North Slope (McKendrick 1991). No one species occurred at all ten study sites, and all but two of these plant species were perennials. The two exceptions were biennials. In addition to these 125 colonizers, approximately 50 other species of indigenous vascular plants were identified that may have potential for colonizing gravel fill in the Alaska Arctic. Approximately 100 of these species merit closer examination for potential applications to vegetating disturbed sites in the Arctic. Grasses are the largest group of colonizers, but a forb, *Epilobium latifolium*, was most widely distributed among the locations. In addition to grasses, the colonizing plants with promise include species of legumes, mustards, composites, and pinks, offering a wide array that could be used to beautify abandoned gravel fill as well as enhance them for wildlife.

Long-term study plans involve seeding approximately 100 species in the botanical garden at the BP Put River No. 1 gravel pad. Nearly two-thirds of that goal was achieved following the 1991 field season. The significance of the diversity of indigenous botanical materials which are believed capable of colonizing gravel substrates in the Alaska Arctic cannot be overemphasized. This is particularly important when considering the popular notion that the arctic tundra inherently lacks resilience to physical disturbances associated with modern man.

Table of Contents

List of Figures

List of Tables

Long-Term Gravel Revegetation Project, 1991 Annual Report

INTRODUCTION

The Gravel Vegetation Study is a three-phase investigation of rehabilitating abandoned gravel fill sites used during exploration and production of oil and gas in arctic Alaska. The three phases of research include: 1) modifying gravel fill to improve conditions for plant growth, 2) identifying indigenous plant species that survive on gravel fill, and 3) monitoring long-term evolution of plant communities and environmental conditions on gravel fill in the Alaska Arctic.

There are areas of overlap among these three phases of research. For instance, in order to measure effects of modifying gravel fill (Phase I) on plant community development, plant indicators must be used. That can be accomplished best by planting species adapted to gravel substrates which are indigenous to the region. Clearly, the objective of Phase II is to identify those plant species. Because both research efforts are occurring simultaneously, it is not possible to wait for the results from Phase II to decide what to plant to measure gravel modification effects in Phase I. Therefore, the two phases must be integrated, for example, by seeding plots to satisfy the requirements for Phase I while seeding some of the same plant species in the botanical garden to meet requirements for Phase II. It is important to recognize the distinction between these two efforts. For Phase I, plants are used to measure differences among various micro-environments created by modifying gravel, and in Phase II, plant survival and growth are measured to evaluate relative performances among species in a uniform environment. From the preparatory work needed to supply the seeds for both of these experiments, additional useful data about seeds of indigenous plant species in the Arctic are obtained that will be needed when setting seeding standards for actual rehabilitation projects.

In this report, we present information and progress primarily on the first two phases. Progress and findings from the third phase, monitoring long-term evolution of gravel fill habitats in the Alaska Arctic, is a separate, comprehensive report in itself.

RATIONALE

Rehabilitating gravel pads and roads in arctic Alaska after those structures are no longer required for oil and gas exploration and production is an important issue for regulatory agencies as well as industry. Compliance standards have not yet been established; permits simply require each site to be rehabilitated to the satisfaction of the permitting agency. This latitude for deciding is desirable, because it will be years, and perhaps decades, before some of these structures are abandoned. Anticipating technology and land agencies' wishes for site rehabilitation that far into the future is very difficult. However, this also leaves agency and industry personnel in an uncomfortable position, open to criticism and possibly even litigation from third-party interests who were most likely not involved with the original planning and development of these projects. It can only be assumed that establishing a functional plant community on gravel fill will be fundamental to future rehabilitation needs, because the stands of vegetation will improve the appearance of these gravel structures and potentially provide habitat for wildlife.

Total removal of gravel is one option, but that would still leave the problem of rehabilitating the dead tundra vegetation which is under these areas of gravel fill. An even greater problem with gravel removal is where to dispose of the fill. It is not always possible to return the gravel to the original mine site. Most of the gravel for the first structures in the Prudhoe Bay region came from river channels. Because stream flow in some source areas has redeposited gravel into the removal site, there is no longer a void in which to place gravel. Returning gravel to river sites could also violate federal wetland regulations and statutes and possibly damage stream channels. Current construction of gravel structures is accomplished with material mined from deep pits, some of which are subsequently flooded and converted to overwintering habitat for fish, a habitat that is rare in the region. Thus, placing used gravel into those sites would violate state fish habitat protection regulations and laws.

The most plausible approach to gravel removal would be to reuse it in some other project that required roads and pads. That means leaving fill in place until it is needed elsewhere. Recent studies (LGL Alaska Research Associates, Inc. 1990, 1991 and Troy Ecological Research Associates 1991) have indicated that in certain seasons some wildlife species use gravel structures and disturbed sites more than they use the adjacent undisturbed tundra. Thus, some of the negative perceptions about gravel fill and losses of wildlife habitat may be overstated. Developing vegetation on gravel structures that would provide habitat for wildlife is an appealing alternative. Obtaining information that will help agencies and industry select *acceptable* and *attainable* vegetation objectives for gravel fill in arctic tundra is the overall goal of this gravel vegetation research project.

Experience in this region has revealed that it requires a minimum of three growing seasons just to determine if mature plants will result from a seeding. Furthermore, some of the most significant plant responses have occurred at test sites seven, ten, or more, years after seeds were planted. To acquire as much information on long-term vegetation changes as possible, this experiment was designed as a ten-year study. The study officially began in 1989, but relevant information was first collected in 1984, while gravel fill used during the second exploration of the National Petroleum Reserve in Alaska (NPRA) was being evaluated (McKendrick 1986). Observations of plant-gravel associations in arctic Alaska began 20 years ago while project personnel were working on a tundra revegetation project in the Prudhoe Bay Oil Field.

Modifying Gravel Fill to Improve Conditions for Plant Growth

Five factors were selected to modify gravel pads for improving their suitability to support vegetation. These five factors included varying: 1) thickness of the gravel fill, 2) compaction, 3) snow cover, 4) topsoil content, and 5) seeded grass. These five factors are variables in the project. Effectiveness of these factors and various combinations of treatments are evaluated by: 1) measuring physical and chemical conditions of the gravel substrate and 2) monitoring plant communities resulting from seeding and natural colonization.

This research is occurring on a restructured exploratory drilling pad near the Putuligayuk (Put) River in the Prudhoe Bay Oil Field (Figs. 1 and 2). Gravel from the nearby Putuligayuk River was used to construct the pad in 1969. It was here that British Petroleum discovered its portion of the Prudhoe Bay Oil Field. After the exploratory drilling ended, the location remained unused until this study began in 1989.

Most gravel structures in the Alaska Arctic are about 1.5 m (5 ft) thick in order to protect the underlying frozen soil (permafrost) and to provide a stable surface for equipment and buildings. Results of a recent study of vegetation on gravel pads indicated an inverse relationship between gravel thickness and plant establishment (Jorgenson 1988). Thicknesses greater than 0.6 m were considered inferior to those 0.6 m and less. There are various physical conditions of the gravel fill that may contribute to this relationship, including moisture availabilities, exposure to winds, lack of snow cover to shelter seedlings during winter, etc. In this project, three thicknesses of gravel were selected for evaluation: 0.6, 0.9, and 1.5 m.

The tundra landscape on the Arctic Coastal Plain is flat and subjected to strong winds that remove snow from elevated areas and deposit it in depressions. Typically, the standing dead plant material from several previous years remains in the tundra plant communities and traps snow. Thus, once a stable plant community forms, the vegetation provides a mechanism for accumulating snow and protecting the overwintering plant parts from desiccation and injury. This is opposite the condition on barren, elevated gravel pads, where snow can be easily scoured from the surface during winter storms. The effectiveness of wind breaks on gravel fill was noted at one location, where small portable buildings created a temporary shelter (1973 to 1984). In that sheltered area, a natural stand of grasses formed and still persists even though the buildings

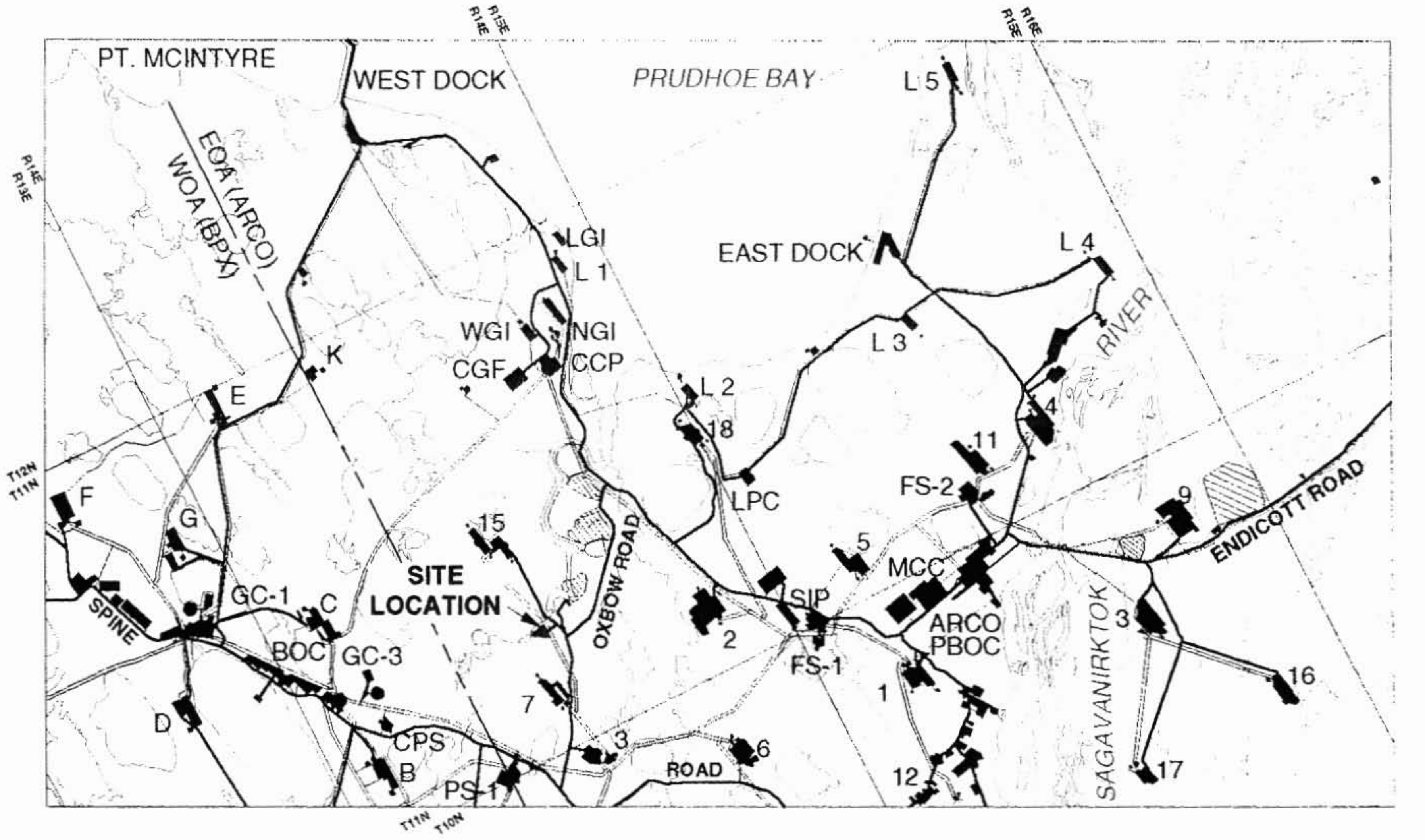

Figure 1

BP PUT RIVER No. 1
GRAVEL VEGETATION SITE

PRUDHOE BAY OIL FIELD

LEGEND

BP EXPLORATION

FIGURE 2
BP PUT RIVER NO. 1
GRAVEL VEGETATION SITE
7/10/91

have been removed for eight years. We concluded that providing temporary protection by encouraging retention of snow cover during the years when plants are becoming established may accelerate formation of plant communities on gravel fill. Two approaches were included in this project to test effects of trapping snow. One was to use physical structures, and the other was to plant a thin stand of grass that would develop standing dead to trap snow, but which would not fully occupy the site and obstruct natural colonization by other vascular plants species. Initially, 0.6-m-high gravel berms were used as the physical structures, but these proved to be ineffective and were replaced by 1.2-m snow fencing.

To be useful for oil and gas exploration and production in the Arctic, gravel fill must shed water and be firm enough to support traffic and the weight of structures. Therefore, gravel fill is compacted to reduce air spaces. This improves the gravel for traffic and supporting loads, but it renders it less hospitable to plant growth because the pore space, essential for aeration and water penetration to supply plant roots, has been reduced. Therefore, tillage of compacted gravel to reverse effects from compaction and restore air spaces was included as a factor in the project.

Typical gravel fill contains relatively few silt- and clay-sized particles. Hence, it has relatively low capacity for retaining moisture and nutrients to support plant growth. Previous work on mine spoils near Fairbanks, Alaska, indicated that as little as 10% silt and clay in the gravel spoils was positively associated with relatively dense stands of trees and other plants colonizing such wastes (Holmes 1982). Investigation of gravel from various sites in the Prudhoe Bay region showed that combined sand, silt, and clay contents varied between 19% and 33% (McKendrick and Holmes 1989). More detailed analyses may reveal that, for the most part, this fraction consists mainly of sand and relatively little silt and clay. Thus, the fine fractions of these gravel fills may contain low proportions of the types and sizes of soil particles that are most suited to retaining available moisture and nutrients for plant roots. There is also considerable variation in the quality of fine fractions among different sources of gravel in the region. At some locations in the Kuparuk field, there appears to be more silt and organic matter than present in the gravels of the Prudhoe Bay locality. Addition of topsoil to increase the proportion of fine soil particles in the surface of gravel fill was therefore incorporated into this project.

Identifying Indigenous Plant Species to Colonize Gravel Fill

The second phase of the study — to determine indigenous plant species adapted to colonizing gravel fill — is required to identify plant materials for vegetating gravel fill. Because most gravel fill is located in moist and wet tundra habitats, which do not contain plant species adapted to the xeric conditions of gravel fill, there usually are no nearby stands of plants to provide recruits to the gravel. Throughout arctic Alaska, however, there are natural xeric and gravel environments along streams and elevated rocky ridges. In these environments, species of vascular plants occur which are adapted to conditions similar to those of gravel fill. The goal of this phase of the project is to identify, collect, and test the suitability of these species for vegetating gravel structures. Once key plant species are identified, efforts to develop supplies of seed for implementing rehabilitation projects can be undertaken.

METHODS

To test each of the factors selected to modify gravel fill, a split-plot factorial experiment was designed. It consists of: three gravel thickness (0.6, 0.9, 1.5 m); two levels of topsoil (8 cm and none); two levels of compaction (tilling and none); snow capture (snow-fenced and not snow-fenced); and two levels of grass (sparsely seeding *Poa glauca* and not seeding) (Fig. 3). The design is complete, with all possible combinations among treatments. However, installing the plots required heavy equipment to restructure the gravel pad. Since maneuvering the machinery around the limited area of the test plots was restricted, random allocation of treatments within blocks was impossible. Therefore, the layout had to be a split-plot for the variables topsoil, tillage, and the three replications.

To identify adapted plant species, appropriate sites were searched for likely candidates. After promising species were identified based on their growth characteristics and seed production potentials, collections of seed were harvested and planted in a botanical garden. Plants that survive will be observed with respect to their aggressiveness to occupy gravel and produce seed under "cultivated" conditions in the Arctic.

Modifying Gravel Fill

To prepare the BP Put River No. 1 gravel pad for this research, cores were systematically drilled on the pad, to measure depths of gravel, in late winter of 1989. Based on those data, the pad was restructured

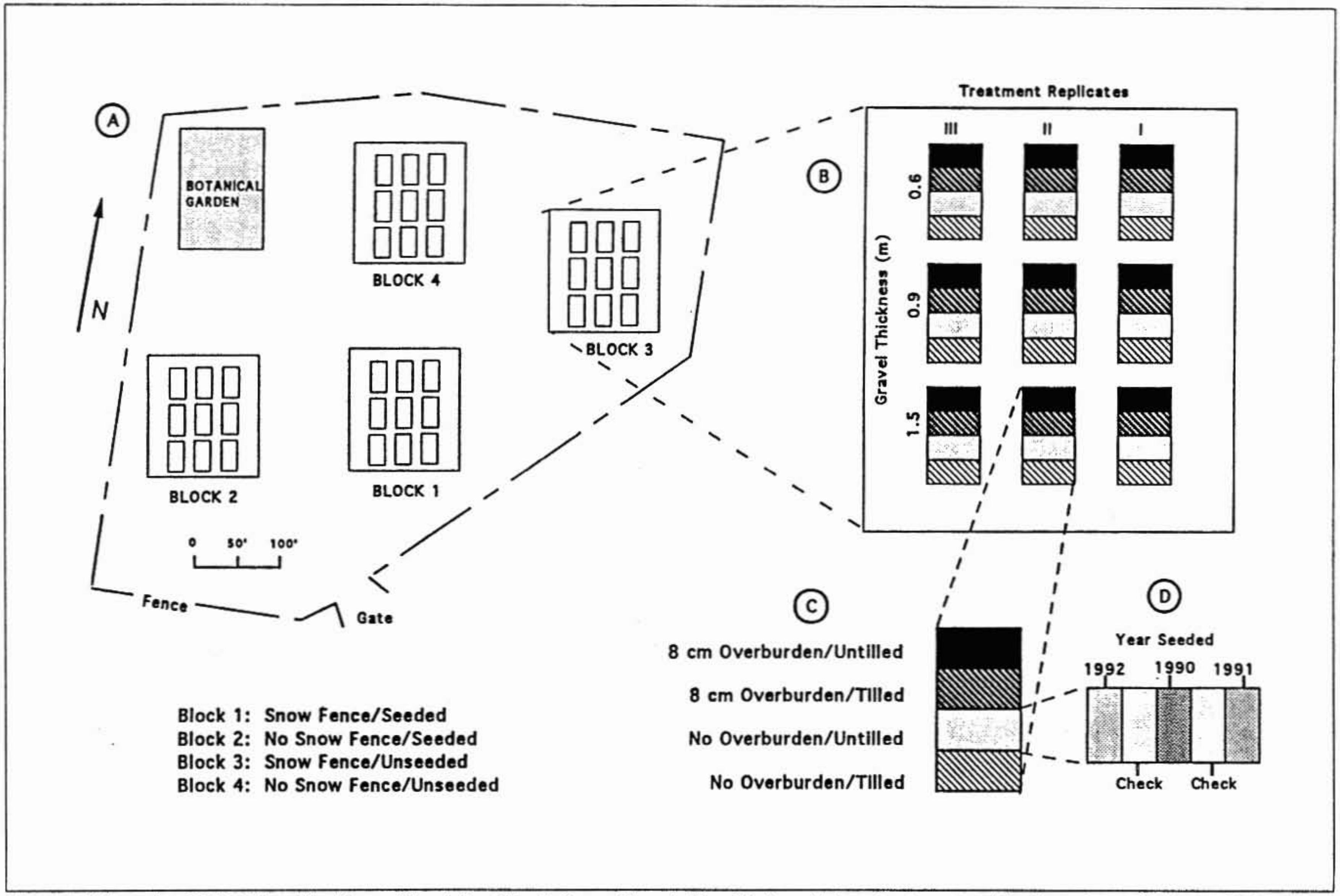

Figure 3. Schematic of BP Put River No. 1 Gravel Vegetation Site: A) General layout of four blocks, which are treatment combinations of snow fencing and light seeding with Poa glauca *(Tundra bluegrass), and a botanical garden containing rows seeded to indigenous vascular plant species; B) Detailed block layout containing all combinations of three gravel thicknesses, overburden additions, tillage, and three treatment replicates; C) Four component combinations of overburden and tillage; and D) Three distinct seeding mixtures of indigenous vascular plant species plus unseeded check zones.*

into four blocks, each with gravel lifts 0.6, 0.9, and 1.5 m thick (Fig. 3). Each lift was compacted to imitate normal work pad conditions and split into three equal portions (replicates). An 8-cm layer of topsoil was applied to half of each replicate. Half of each topsoil and non-topsoil treatment was tilled to reduce effects of compaction. There are 144 experimental units among these four blocks. Two of the blocks were sparsely planted with *Poa glauca* (glaucous bluegrass), variety Tundra at 13 seeds/m^2, to provide microsite snow cover. Gravel berms (0.6 m high) for collecting snow were constructed on two blocks, one of which was planted with *Poa glauca*. These berms proved ineffective, failing to create snow cover across the plots. Therefore, 1.2-m snow fences were installed in October 1990 (Fig. 4). These fences proved effective for capturing snow. All treatment areas in all four blocks were fertilized with N-P-K at 57-35-35 kg/ha (elemental equivalent). Each of the 144 experimental units was further divided into fifths — three different planting plots, each separated by a "control" plot — for a total of 720 plots from which vegetative data are collected (Fig. 3). Planting years consist of 1990, 1991, and 1993, with two plots left unplanted as check plots.

The entire experimental area was fenced to exclude vehicle traffic, grazing caribou, and other unwanted intrusions. The perimeter fence has proven effective; however, a bear entered the area, presumably by crawling between the bars on the metal gate, and wandered about the enclosure during the spring of 1991. In spring, geese also fly into the area and graze on the seeded plots that are barren, i.e., blocks without snow fencing.

Measuring Physical and Chemical Conditions of the Gravel

Soil (Gravel) Sampling. To measure the effects of modifications on the gravel fill, substrate samples were collected for physical and chemical analyses in the laboratory. On 12 July 1990, a baseline collection of gravel was taken from each of the 144 experimental units at the site. Gravel/soil samples were collected from at least six different locations of the unplanted portions of each experimental unit. These six subsamples were combined, then placed in two 1-gallon Ziploc® bags. The samples were taken to the University of Alaska Fairbanks laboratory in Palmer, where they were air-dried and sieved. The portion retained on each sieve and that in the bottom pan (<2-mm size, or fine fraction) were weighed to the nearest 0.1 g. The <2-mm soil fraction was split with a soil sample splitter, and has been stored for further analysis. The >2-mm fraction was discarded.

During the summer and autumn of 1991, an abnormal red color was observed in the leaves of some plants in plots on the gravel pad. This color is sometimes an indicator of either phosphorus or potassium deficiency, and it can be induced by low temperatures. All three conditions were plausible. Gravel was sampled from planted, and unplanted portions of 12 experimental units, and leaf tissue samples were taken from four experimental units for laboratory analyses.

By definition, ***bulk density*** is the specific weight of structured soil, which contains air spaces and natural pores. This measure is not to be confused with the *specific weight* of soil solids. Bulk density is expressed as grams oven-dry weight per centimeter^3. The lower the bulk density, the greater the volume of air and/or organic matter in the soil. Thus, for gravel fill, it is an index to the degree of compaction of the material and inversely related to the porosity and water infiltration capacity of the gravel. A bulk density of 1.2 to 1.3 g/cm^3 is considered normal for a typical mineral soil for cropland production. Highly organic soils will have bulk densities less than 1.0 g/cm^3, i.e., they are lighter than water. A bulk density of 0.1 g/cm^3 is not uncommon for peat soils. For very stony soil, the bulk density will approach, and often exceed, 2.0 g/cm^3 as the mass of rock becomes the dominating feature in the soil. The average specific weight for rock in the earth's mantle is about 2.65 g/cm^3.

Soil bulk density is calculated from measurements of a volume of soil divided by its oven-dried weight. In our work, volume was measured with a VOLU-VESSEL, a device which consists of a transparent, sealable graduated cylinder with a thin-walled bladder at the bottom and a hand aspirator at the top. To use the device, the cylinder was secured over a 10-cm-diameter hole in a metal plate. The plate was held in place at each sampling site by steel pins driven into the soil. After partially filling the graduated cylinder with water, the cylinder was pressurized by pumping air from the aspirator and forcing water from the cylinder into the bladder, which expanded to occupy any void below the hole in the metal plate. Because soil surfaces are uneven and do not conform exactly to the surface of the metal plate, two measurements were taken: 1) to establish a reference volume of the undisturbed soil, and 2) to measure the volume of the sample removed from the soil (gravel) surface. By subtraction, the sample volume is calculated.

Volumes were obtained by aspirating the hand pump until a stable water level was observed in the graduated cylinder. After the first reading was obtained, soil (or gravel) under the hole in the plate was carefully excavated. Because the gravel surfaces were compacted, removing gravel samples required careful excavation. A cold chisel and hammer were used to loosen the gravel, which was then removed with a spoon and placed in labelled, doubled resealable (Ziploc®) bags. Then the second volume reading was taken, to measure the volume of the gravel that had been excavated. Volume of the excavated gravel sample was calculated by the difference between water volumes of the first and second readings. The weight of the gravel was determined after drying 48 hours at 105°C. Bulk density was calculated by dividing the field-measured volumes (cubic centimeters) by the laboratory oven-dried weights (grams) of the respective excavated samples.

In the course of obtaining bulk density data, soil moisture was also measured (gravimetrically) for all soil and gravel samples. Samples which had been sealed into plastic bags at the time of collection were taken to the laboratory. Fresh weights were measured, and then samples were oven-dried for 48 hours at 105°C. The weight loss between the fresh and the oven-dried weights represented moisture content in these samples. The moisture weight was divided by the oven-dried weight of soil to obtain percent soil moisture, i.e., (weight of water/weight of oven-dry soil) x 100. This is the standard method for measuring soil moisture. Technical reports on studies from the Alaska Arctic and elsewhere by environmental scientists and technicians often contain soil moisture data that has been incorrectly calculated, i.e., (weight of water/ (weight of soil+water)) x 100). The magnitude of the error increases with increasing wetness of the soil; thus, the seriousness of these errors becomes most pronounced for data from arctic wetland soils. In those soils, the water content often exceeds 100%. This is particularly true where organic matter is a major component and permafrost is present. If the *incorrect* formula is used to calculate soil moisture, the percentage may never exceed 100%, a percentage that should appear relatively frequently in data for wet soils of the Alaska Arctic.

Other measurements are planned to evaluate the conditions of the gravel substrate, including: moisture desorption curves to measure water-holding capacities at various moisture tensions and particle size analysis of the fine fraction to determine texture. Cation-exchange-capacities, pH, and availabilities of nitrogen, phosphorus, and potassium will be used to measure nutrient-holding and supplying capacities of the fine fraction. In some instances, organic matter may be a significant feature to measure. The gravel and overburden from the BP Put River No. 1 gravel pad site have been sampled and prepared for laboratory analyses. Data from those samples will be used to determine baseline conditions prior to the initial application of fertilizer in the fall of 1989. The relevant samples have been archived, and these measurements will be obtained as labor allocations shift from field plot establishment and seed collection to monitoring vegetation responses.

Routine soil fertility and salinity measurements will be conducted in the laboratory in Palmer. Samples for these analyses have been collected, prepared for laboratory analyses, and placed in storage. After all the samples have been collected, they will be submitted for laboratory analysis. Moisture desorption curves will be performed at another laboratory. The particle size analyses are scheduled to be conducted in-house. The moisture desorption curves and particle size analyses are physical measurements and are not affected by storage time of samples. Efforts for the seed collecting, cleaning, and testing were allocated for the first 3 years of the project in order to establish the sequence of plantings on the gravel plots. The timing of seeding is critical to the success of the long-term evaluation of vegetation. Obtaining gravel physical data is not time-dependent, because those features remain unchanged during storage.

Measuring Snow Cover. To measure the effectiveness of snow fencing for capturing snow during winter on the plots, a snow survey was conducted on 7 and 8 May, 1991. Standard snow survey equipment, loaned to us by the USDA Soil Conservation Service, Anchorage, Alaska, was used. The equipment consisted of a tube with cutter, used for extracting cores from the snowpack, and a cradle and scale, used for weighing the core and tube. The diameter of the tube and the scale were designed to weigh snow cores in units equal to inches of water, which were then converted to metric units. This measure was obtained from the net weight of the core, i.e., by subtracting the weight of the empty tube (tare weight) from the weight of the tube and snow core. Data obtained during this snow survey included: location, depth of snow, length

Figure 4. Installation of posts for a snow fence on Block 1 of the BP Put River No. 1 gravel pad experimental area (25 September 1990).

of core, weight of tube and core, tare weight, centimeters of water, and percent density of snow. Percent density was calculated by dividing the water content by the depth of snow and multiplying by 100. Core length and percent density were obtained at each sampling location while the snow survey was conducted and used to determine if the extracted core was a reliable sample. Established criteria dictate that sample densities should not vary more than 3% on a uniform site; when a core density differed more than 5%, it was discarded and another sample taken.

Snow freezing in the tube creates problems with sampling and usually occurs when the temperature of the tube is above the freezing point for water. Consequently, care was taken to ensure the tube was clean before each sample was extracted. Gloves were worn at all times to minimize difficulties with snow adhering to the tube because of warming through handling. Also, to reduce chances for snow freezing to the tube's surface, the tube was cooled adequately before use and pushed rapidly through the snowpack without stopping until the cutting edge met the ground surface.

Snow accumulations on plots without snow fences were subsampled and combined, because it was impossible to read the balance accurately if the water content was less than 5 cm in a single sample. Ten subsamples were collected and combined into a tared bucket for weighing. The tare weight was subtracted from the combined weight of the bucket and collection of snow cores to calculate the net weight of snow in the collection of subsamples. Average weight for the subsample was calculated from the net weight of the collection of cores divided by the number of subsamples (10). These data were used to calculate the average centimeters of water contained in the snow.

Monitoring Temperatures. Soil and air temperatures and wind speed and direction among treatments at the BP Put River No. 1 gravel pad were not being monitored in 1991. However, air, water, pond sediment, and soil temperatures at locations used during a previous research project were monitored. Air and soil temperature data from those stations have been used for evaluating year-to-year variations in growing conditions for the current study. These data revealed general growing conditions among years. They have proven useful not only for explaining variations among years in plant growth of species seeded on the gravel pad, but also for interpreting inter-annual variations in growth, flowering, and seed production by natural stands of plants from which seed was harvested for this study.

Air and soil temperatures were monitored from 1988 through 1991 at a coastal site (Big Skookum) and at a site in the foothills of the Brooks Range (MP 62). The locations of these sites are shown in Figure 5. Automated temperature instruments (Datapods®) manufactured by Ominidata, Inc. of Logan, Utah, were used to record temperature data. Each Datapod® has two temperature sensors (thermistors), which were placed to detect temperatures in the air and soil at each site.

Lead wires for sensors measuring air temperatures were taped to wooden stakes in a manner that prevented the sensor from touching these stakes. Solar radiation shields were installed on all air temperature sensors in 1991. These sensors were retained in the field year-round to maintain consistency in locations of sensors among seasons. As early as possible during each growing season, sensors were checked for accuracy with hand-held instruments. This validation was performed as soon as field conditions permitted (after substrates thawed). Any sensors that produced questionable data were replaced.

Moisture inside the Datapod® case prevents the instrument from operating properly; consequently, Datapods® were placed in steel ammunition boxes that could be hermetically sealed. The boxes were fastened to steel fence posts driven through the active layer of either pond mud or tundra soil, depending on the Datapod's® location. Even though these Datapods® were supposed to remain moisture-proof when properly closed, a small can of desiccant granules was placed in each ammunition box and a desiccant capsule was placed inside each Datapod® case to absorb any moisture that may have inadvertently been trapped during installation of these instruments. Whenever the instruments were serviced during the course of the field season, the desiccant supply was replaced if it showed signs of collecting moisture.

Datapods® were programmed to scan sensors at 5-minute intervals. Readings were averaged hourly to give a single datum. These means were stored on E-Prom silicon chips which were removed and replaced with fresh data storage chips when new memory capacity was needed. The E-Prom chip's capacity was 42 days when the Datapod® was programmed as described. The readings were checked periodically to verify that the Datapods® were functioning properly. During data processing, the field records were used to authenticate the instrument measurements to further verify sensor functioning was valid.