Data from the chips were downloaded to a computer at the end of the season. The data files were read from the microchips and saved as ASCII files. The individual file from each microchip was imported into WordPerfect® 5.1 and combined to produce a single annual file for each site. Because the hour of recording represented the mean value of the previous hour, the identifier column was moved one hour later than shown in the raw temperature data. Edited files were saved in the ASCII format and read into SYSTAT® (Wilkinson 1988) and line graphs produced for each site by year. Summaries of positive and negative degree hours were generated for each month in which we obtained complete temperature records. The STATS module in SYSTAT® was used to summarize the temperature data in terms of degree-hours.

### *Measuring Effects of Modifying Gravel Fill with Plant Indicators*

This section contains descriptions of procedures that had to be followed to obtain plants for evaluating various modifications of gravel fill. To measure the effectiveness of these modifications to gravel fill on plant community development, mixtures of indigenous plant seeds were planted in 1990 and 1991 to 1/5 of each of the 144 experimental units (plots - Fig. 3). The plans dictated planting three separate seed mixtures into subdivisions (1/5) of each experimental unit, to allow for as much variation among potential colonizers as possible during the course of this experiment. Because indigenous plant seed for these mixtures had to be found and generally hand-harvested, availability of manpower and facilities to acquire and prepare these mixtures precluded planting all mixtures in a single year. Therefore, the planting portion of the work was spread over a 3-year period. This will permit nine growing seasons to observe the first planting and at least six growing seasons to observe the final planting. The first planting was completed in June, 1990, using seed harvested the previous autumn (1989). The second planting was completed in June of 1991, with seed harvested in the autumn of 1990. Seed was harvested in the autumn of 1991, for the third and final planting, scheduled for June of 1992. Failure of native stands to produce sufficient seed in 1991 prevented planting in 1992. The final seeding was rescheduled for 1993.

This will leave 2/5 of each experimental unit unplanted, except for the light seeding of *Poa glauca*, which was applied to only two of the blocks. These two unplanted plots in each experimental unit will be used to observe voluntary establishment of plants to the area. Initially, invasion by vascular plants will be from seed produced by the naturally occurring stands of gravel colonizers along the nearby Putuligayuk River. As our seeded stands mature, we anticipate they will contribute propagules to the unplanted plots. This results in a total of 720 plots among the 144 experimental units (Fig. 3).

**Deriving Seed Mixtures.** It is critical for research purposes to know how many viable seeds are applied to a given plot, in order to interpret the results in terms useful for actual rehabilitation projects. It is essentially the foundation for the rest of the experiments. Industry, contractors, and agencies eventually have to write specifications for such work, and they must know how much seed to apply to achieve a desired objective. Therefore, a significant amount of time was spent cleaning seed, measuring germination rates, and assuring that identical amounts of seed were allocated into each plot.

Seeds were collected in the field after ripening but before dispersal. Seeds were harvested by various methods, including hand-picking, cutting with shears, and mechanical harvesting, depending upon the type of seed, plant growth form, and stand density and size. A mechanical harvester was designed and built by project personnel for use in harvesting dense, even stands (Fig. 6). Collections included inflorescences, leaves and other non-seed components of plants. These collections were usually placed in either 1- or 5-gallon plastic buckets during collection and then transferred to cloth bags which were labelled with the species name, harvest date, and location of origin. Very small seeds which could pass between the mesh of the cloth bags were placed in paper bags which had their seams taped. All bags were hung in the field laboratory and air-dried before shipment to Palmer for processing. Drying is important to prevent molding of the wet plant material, which may destroy seed viability, and to terminate the seed filling phase, which must be done in order for seeds to germinate.

At Palmer, the field-collected material was removed from the bags and threshed using a hand scrubber. Threshing removed seeds from flower parts and ovules from ovaries. Extraneous plant material was then separated from the seeds. Hand screens were used for this separation. The openings in the screens range in size from very small to large and in shape from round to linear to accommodate various sizes and shapes of seeds. Appropriately sized and shaped

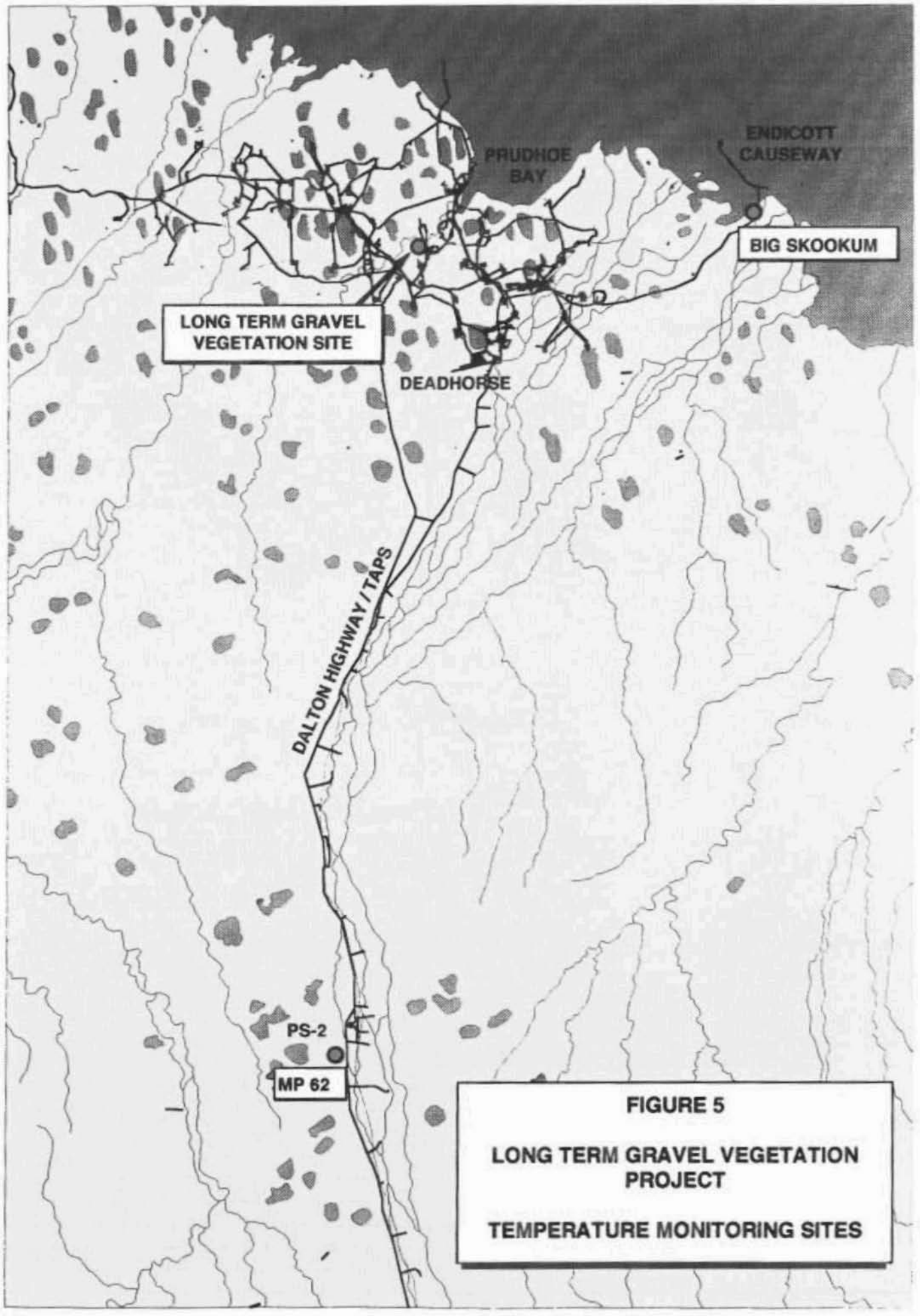


**FIGURE 5**

**LONG TERM GRAVEL VEGETATION PROJECT**

**TEMPERATURE MONITORING SITES**

Figure 6. Collecting *Puccinellia langeana* seed with a mechanical harvester (24 August 1989).

screens were selected, usually on the basis of seed size. A screen size somewhat larger than the seed was initially used to remove the bulk of the vegetative plant material. Pieces of leaves, stems, chaff, and other debris were trapped by the screen and discarded while the seed and finer particles passed through into a collecting pan. This screening process was repeated several times for some seed collections, depending on the nature of these materials.

Another hand screening was needed to separate the seed from the smaller debris. For this, a screen size smaller than the seed was selected. The fine debris consists of soil particles, fragments of vegetative plant parts, and sometimes insect larvae. The rejected portions were periodically examined under a light lens to verify there were no losses of seed among them before being discarded.

After hand screening, the seedlot was passed through a mechanical separator that used a variable air flow to separate the seed from debris by gravity. This separator forces air through a vertically positioned, clear, 9-cm-diameter Lexan cylinder. There were baffles at the top of the cylinder, into which the lightest particles became trapped. The heavier particles were retained in the bottom of the cylinder. This operation required skill and experience to gauge the air flow sufficient to carry only the light material (chaff) and not the seed to the top of the cylinder, where it was caught in baffles. At this point, most seedlots were judged to have been cleaned as much as was practical for our research purposes.

Seeds with long trichomes (hairs) that float easily on air currents in nature had to be delinted (Fig. 7). Without delinting, it would have been difficult and perhaps impossible to handle, test, and plant the seed because these seeds are easily carried with the slightest of air movements. Examples were species of *Salix*, *Epilobium*, *Senecio*, and similar types.

To delint seed, the collection was placed in the delinter, after hand threshing to loosen the ovules from the ovaries. The delinter consisted of a metal cylinder approximately 1 m in length, through which an airflow was maintained from a compressor. Inside the cylinder a power shaft extended the full length and supported a drum with a diameter about 10 cm less that the inside of the cylinder. The outside of the drum had a series of small (about 30-mm diameter) all-thread rods projecting about 5 cm perpendicular from the drum surface. The inside of the cylinder had a similar set of all-thread rods that were offset so that as the drum rotated these small rods intermeshed but did not touch. The interior of the cylinder was accessible from a small portal on the top. Seeds to be delinted were placed in the cylinder and the door sealed. The airflow and power to turn the drum were started and allowed to operate for as long as needed to remove the trichomes from the seed. This required about 30 or more minutes per collection, depending upon the seed and trichomes. The light seeds were forced by the airflow into the area between the drum and the inside of the cylinder, where the all-thread rods were meshing. As these seeds passed among the rods, trichomes were broken and removed. Once the seeds lost their trichomes, their buoyancy decreased, and they fell to the bottom of the cylinder. The cylinder was mounted on a stand at an angle so that one end was lower than the other. By gravity, the seed moved to the lower end of the cylinder, where it was removed through a trap door, after the airflow and power were stopped. Portions to be discarded were examined to ensure seed was not inadvertently lost. Usually, after delinting, seeds were adequately cleaned (Fig. 7). If that was not true, screening was used to further separate ovules from debris.

It was necessary to handle each seedlot in these collections separately to prevent mixing among species and various source areas. Throughout all these operations, it was critical that each vessel, tool, and piece of equipment was thoroughly cleaned between processing the various seedlots. Otherwise collections would have become contaminated with seed from other species, invalidating the scientific integrity of the research.

After each seed collection was cleaned to meet the requirements of the experiment, purity was determined by examining a portion of the seedlot under a light lens. An aliquot of seed was placed on a tray, and the amount of foreign material was estimated with respect to the amount of seed. A few collections were separated by hand, and the portions of impurities and seed were weighed to gravimetrically measure purity. Purity was the percentage of the cleaned collection composed of ovules, i.e., the proportion of the collection that was actually the specified seed and not other seed, vegetative particles of plants, or inert material (Figs. 8, 9, and 10). To become certified, seedlots must be inspected either by government agencies or recognized seed-grower associations, according to state laws. The purity portion of the certification label must list all foreign matter, especially seed from undesirable plants. Our impurities were usually inert material, as opposed

to foreign seed. However, when seed was being collected and during threshing and cleaning, inadvertent mixing of plant species occasionally occurred (Fig. 8).

The seedlots were individually weighed after purity was determined. Each seedlot was then placed in a labeled jar(s), and the pertinent data recorded on inventory records. These jars of seed were kept frozen for at least a two-week period prior to undergoing germination tests. Freezing was one step in the conditioning process to prepare seeds for germination tests.

Stratification was also used to induce germination. *Stratification* is the term often used with reference to various conditioning processes used to break dormancy and allow seeds to germinate. The term *stratification* originally was used to describe a method for conditioning temperate and boreal zone tree seeds by alternating layers (strata) of seed and moist sand in a box and storing this in a cold room for several weeks or months to simulate winter conditions in the field. A cold treatment is often needed before plant seeds indigenous to boreal and arctic climatic zones will germinate. There are many treatments and combinations of treatments that will break dormancy of seeds. For this project, we selected a method involving household bleach and a short storage period under refrigeration to prepare seeds for germination. In a previous study, this treatment sequence was tested and found effective for *Arctophila fulva* seed from the study area (McKendrick 1991). However, it may not be the most effective for seed from other plant species in this collection.

Not all of the seeds planted will actually germinate. Some seeds are immature and unable to germinate. Others have been damaged by insects and during handling and have died. Tests for germination percentage in this study produced data ranging from zero to nearly 100%. Before a seed mixture could be formulated, the percentage of ovules (seed) that had the potential to germinate was determined for each seedlot. This information was obtained by performing germination tests on each collection using Alaska Seed Growers, Inc. procedures.

The quantities of seed used for planting were estimated by weighing a known number of seeds and calculating the number of seeds per gram. Because seed size and weight vary among and even within species, it was necessary to determine the number of seeds per gram in each seedlot.

Seed weights were determined during the testing for germination. After the freezing treatment, 320 seeds were removed from each storage jar in the collection. These were weighed on an analytical balance and the weight recorded on the inventory data forms. The 320-seed aliquot from each lot was soaked for 5 minutes in pure laundry bleach (Clorox®), then rinsed in tap water for 5 to 10 minutes. Three hundred seeds from each seedlot were placed in Petri dishes on 8 x 8 cm blotter pads. Each blotter pad had 100 divots in its upper surface, and one seed was placed in each divot. Three Petri dishes were prepared for each seedlot. The extra seeds from the 320-seed aliquot were discarded, after the needs for germination testing were fulfilled. Blotter and seeds were moistened with a solution of distilled water and Captan® (0.5 g Captan® powder/liter water) and given a chill-treatment by placing the Petri dishes in a refrigerator at ≈4.3°C for six days. Then the Petri dishes were placed in a germination cabinet (germinator) to encourage seeds to germinate.

The germinator was set to cycle for a 24-hour period, with 16 hours of light @ 20°C, followed by eight hours of darkness @ 13°C. Progress of these tests was monitored daily. The blotter pads were kept moist with the Captan® solution to control mold. Each day, the number of seeds that had germinated in each Petri dish were counted and recorded on a laboratory form. Germinated seeds were removed from the dishes to prevent seedling growth from overcrowding the blotter and encouraging mold. The tests were continued until germination ceased for three consecutive days. The average number of seeds per hundred that germinated among the three replicates within each seedlot was the measured germination percentage for that seedlot.

Major portions of some seed lots failed to germinate during the testing period, even though the seed appeared fully formed and mature. Seed dormancy was believed to be the cause for these low germination results. Seed dormancy is particularly common for certain plant families such as legumes and crucifers. It is believed to be a survival characteristic for plant species, especially on wildlands (ranges and forests) in marginal climates. It prevents the entire seed crop from germinating simultaneously, which would occur whenever suitable environmental conditions developed. If a portion of seeds remained dormant, the species could survive periods when unfavorable conditions might otherwise eliminate all young seedlings. Seed dormancy is undesirable in agricultural crops, because under cropland conditions, uniform germination is necessary for efficient management of plants. Consequently, efforts to either eliminate or

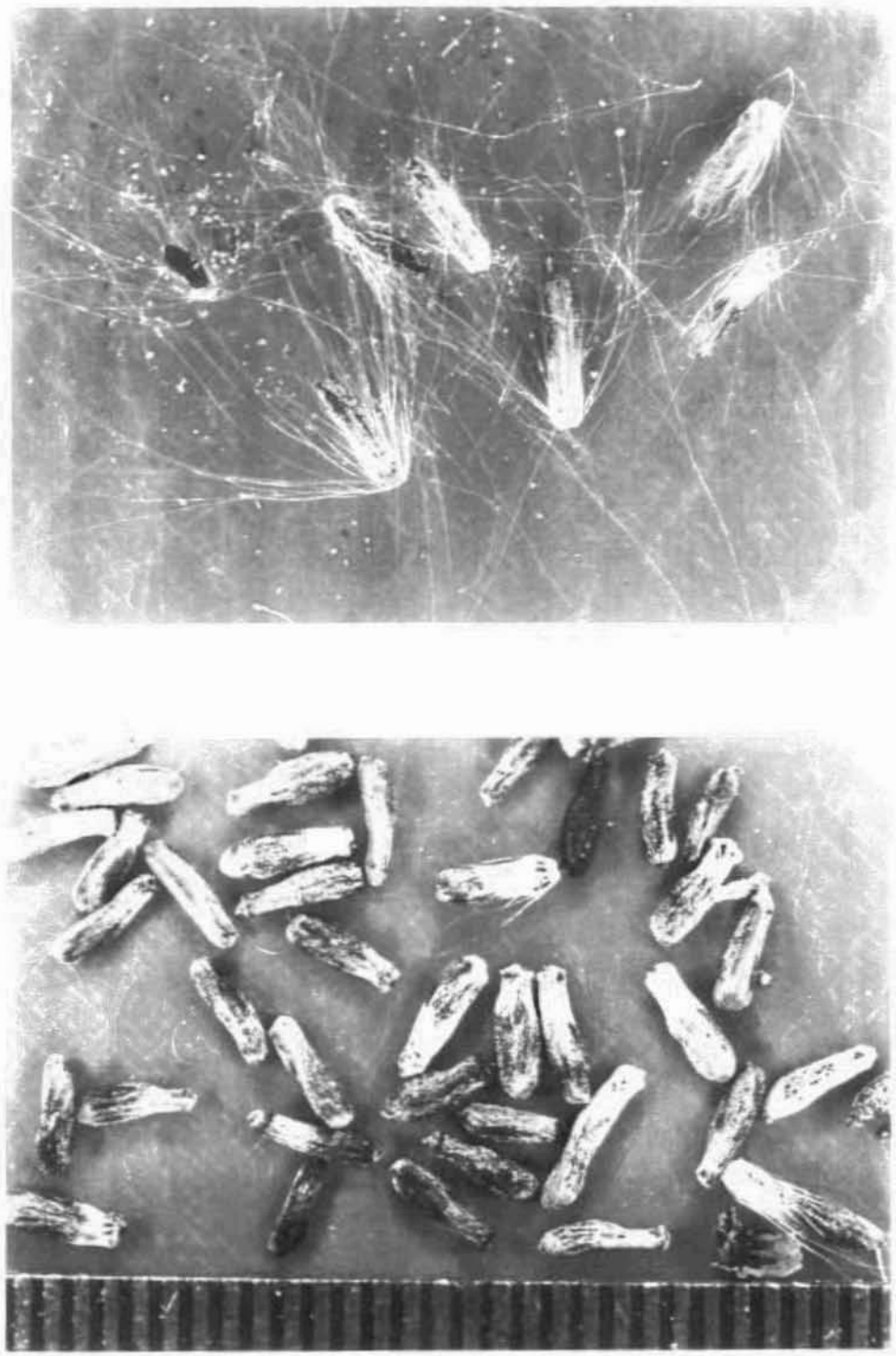

Figure 7. *Salix ovalifolia* seed with trichomes intact (upper) and removed (lower).

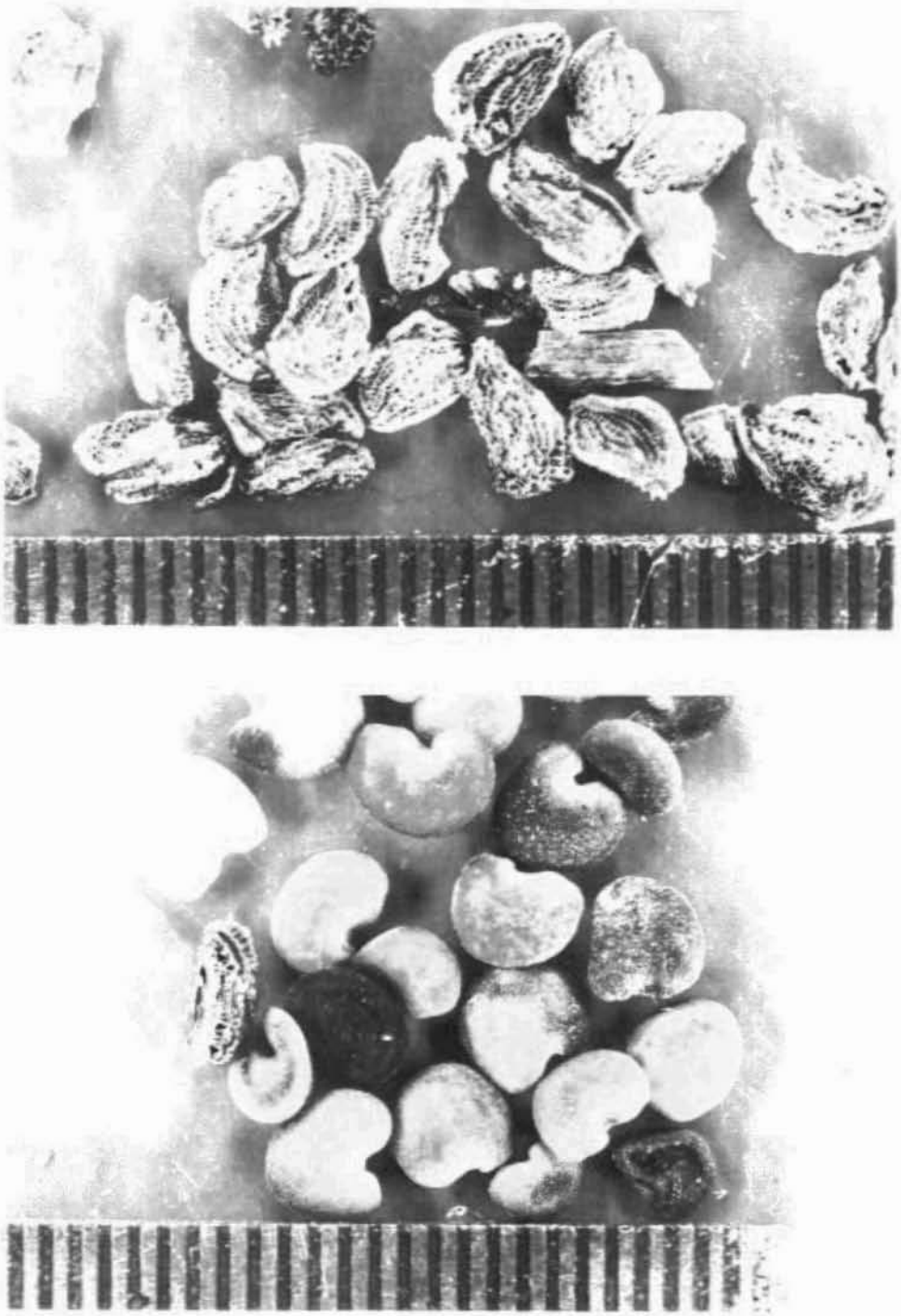

Figure 8. *Pedicularis capitata* (upper) and *Oxytropis borealis* (lower) seeds. Notice the *Pedicularis* seed mixed with *Oxytropis*.

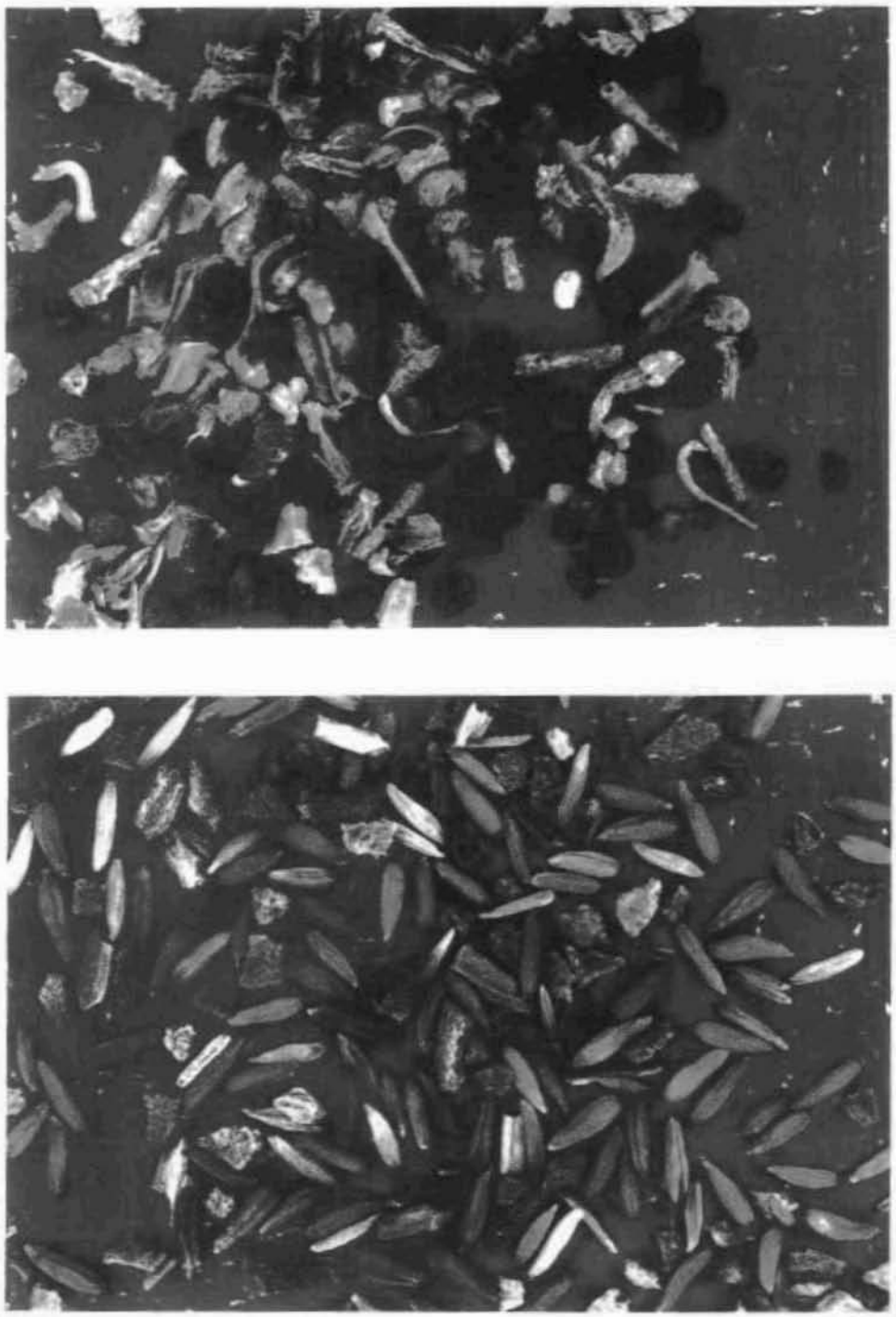

Figure 9. Vegetative fragment impurities in *Minuartia obtusiloba* (upper) and *Epilobium latifolium* (lower) seedlots from two collections of indigenous seed.

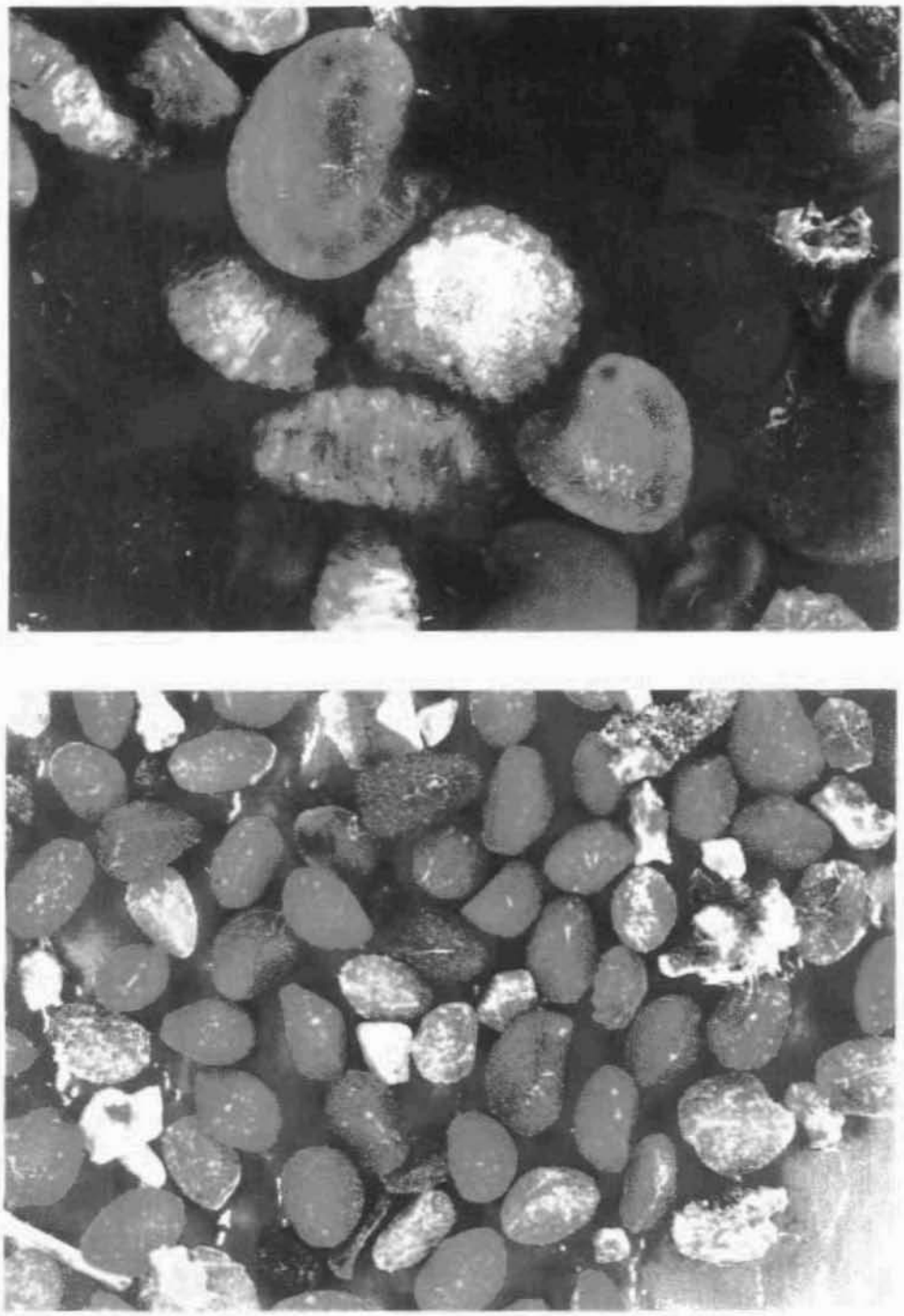

Figure 10. Insect larvae (upper) and sand and plant fragment impurities (lower) in seedlots of *Hedysarum mackenzii* and *Androsacae chamaejasme*, respectively.

sharply reduce dormancy through plant breeding have been developed for agronomic and horticultural plants. An experiment was included in this study to determine if dormancy was a factor that might explain low germination percentages observed for some of these seedlots.

Seed from five species — a grass (*Alopecurus alpinus*), a sedge (*Carex maritima*), one crucifer (*Braya pilosa*), and two legumes (*Hedysarum mackenzii* and *Astragalus eucosmus*) — was selected for testing dormancy-breaking treatments. The experiment included one mechanical and four chemical (including water) treatments to reduce seed dormancy. All plant species were from North Slope indigenous seedlots. The seedlot of *Braya* was collected on 28 August 1972, while we were conducting tundra revegetation experiments at Prudhoe Bay, Alaska. The remainder were from collections of the 1990 seed crop.

In this experiment, seeds were passed through a scarifier two times. Mechanical scarification is used to either weaken or degrade the indurated seedcoat and permit imbibition of oxygen and water. The scarifier is a hand-cranked device in which exteriors of seeds are abraded as the seed passes between two pieces of sandpaper. One strip of sandpaper is held stationary on a pressure plate, and the other is mounted on a rotating drum. The pressure plate is forced toward the rotating drum with an elastic band. The sandpaper surfaces abrade seedcoats, producing openings for air and water to enter so the embryo can germinate.

Chemical scarification is used to degrade seedcoats as well as alter certain biochemical controls that may be inhibiting germination. In addition to wetting seed with tap water, seeds were soaked in three chemicals (household bleach [Clorox®], hydrogen peroxide, concentrated sulfuric acid) and irrigated with a solution of potassium nitrate. The bleach treatment continued 5 minutes, followed by rinsing with tap water to remove the chemical. Seeds were soaked in 35% hydrogen peroxide for 15 minutes, followed by a thorough tap water rinse. The sulfuric acid treatment included soaking seed for either 5 or 15 minutes in 96.5% concentrated $H_2SO_4$, followed by a 5-minute treatment of sodium bicarbonate (50 g/1,000 ml water), and finally a thorough tap water rinse to remove the chemical residues. The potassium nitrate treatment consisted of wetting the seeds initially with 0.2 g $KNO_3$/100 ml water, then watering them with the solution as needed during the germination tests.

All seedlots in all germination tests, except those given the potassium nitrate treatment in the dormancy-breaking experiment, were kept moist with a Captan® watering solution during the germination trials. Captan® was inadvertently omitted from the potassium nitrate solution, and the error was not detected until it was too late to correct. This error may not have significantly altered the germination test results, unless mold growth killed embryos before they produced radicals. The appearance of radicals was used as an indication of germination.

In the dormancy-breaking experiment, one treatment with only the Captan® watering solution served as a control. Seeds for germination tests were moistened with the Captan® solution and chilled in a refrigerator @ ≈ 4.3°C for six days before being placed in the germinator. There were two combinations of temperature settings used for the germinator. The warmer setting exposed seeds to a 16-hour light period @ 20°C, followed by an 8-hour dark period @ 13°C. The cooler setting exposed seeds to a 16-hour light period @ 15°C, followed by an 8-hour dark period @ 5°C. All seedlots in our collections were initially tested for germination percentage using the higher setting. However, during the dormancy experiment, the lower setting was used, to more closely represent field conditions of the North Slope. This also provided a limited comparisons of germination percentages between the two temperature settings.

Results from the dormancy experiment were inconsistent among species of plants (Table 1). *Alopecurus*, *Hedysarum*, and *Astragalus* each responded positively to the acid-soaking treatments, even though the period of soaking was reduced for the grass seed to prevent destruction of the ovule. Compared to the control, *Alopecurus* germination increased six to seven times, *Astragalus* germination increased 19 to 27 times, and *Hedysarum* (bare seed and in loments) increased approximately two times with acid scarification.

The potassium nitrate treatment and Clorox®, in combination with the warmer germination cabinet setting, yielded the highest germination for the ≈20-year-old *Braya* seeds. Mechanical scarification improved germination in the bare seeds of the two legumes, *Hedysarum* and *Astragalus*, although not as much as did the acid scarification. Conversely, mechanically scarified seed of *Hedysarum* in loments germinated better than seeds treated with acid. Germination of *Carex maritima* seed increased markedly with the Clorox® treatment, when seeds were germinated at the

*Table 1. Summary of germination percentages for five indigenous plant species collected on the Alaska North Slope and treated with one mechanical and five chemical procedures to break dormancy.*

| *Genus species* Source Area Date | Captan® & Water Only (Control) | [1]$KNO_3$ Only | 35% $H_2O_2$ 15 Minutes | Clorox® 5 Minutes + Captan® & Water | | | 96.5 % $H_2SO_4$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | [2]Warm Test | [3]Cool Test | Mechanical | 5 Min. | 15 Min. |
| *Alopecurus alpinus* 1972 Haul Road 10 September 1990 | 10.5 | 5.0 | 7.5 | 5.3 | 5.0 | 5.0 | 75.5[4] | 63.0[4] |
| *Carex maritima* East Dock 9 September 1990 | 0 | 0.5 | 1.0 | 23.6 | 0 | 0.5 | 0.5 | 1.0 |
| *Braya pilosa* 1972 Haul Road 28 August 1972 | 0 | 20.0 | 4.5 | 22.7 | 5.5 | 0 | 0 | 0 |
| *Hedysarum mackenzii* (bare seed) MP 369 Dalton Hwy. 6 August 1990 | 13.5 | 9.5 | 15.0 | 6.0 | 18.0 | 24.5 | 26.5 | 28.0 |
| *Hedysarum mackenzii* (seed in loments) MP 369 Dalton Hwy. 6 August 1990 | 11.5 | 9.0 | 10.0 | 5.0 | 11.0 | 31.5 | 27.0 | 23.5 |
| *Astragalus eucosmus* MP 399 Dalton Hwy. 5 August 1990 | 3.5 | 2.5 | 3.5 | 4.0 | 7.5 | 80.0 | 66.5 | 94.5 |

[1] Captan® was planned for this treatment, but was inadvertently omitted.
[2] In this germination test each 24-hour period alternated between 16 hours under lights @ 20°C and 8 hours in darkness @ 13°C.
[3] In this germination test each 24-hour period alternated between 16 hours under lights @ 15°C and 8 hours in darkness at 5°C.
[4] Sulfuric acid treatments for *Alopecurus alpinus* were reduced to 0.5 and 2 minutes, respectively, for the 5- and 15-minute treatments, because the longer treatments destroyed the *Alopecurus* seeds.

warm temperature range. All other treatments of *Carex* seed appeared insignificant for improving the germination for this species. Germination of the bare legume seeds improved slightly under Clorox® treatment with reduced temperatures in the germinator. The hydrogen-peroxide treatment of the bare *Hedysarum mackenzii* seeds may have improved germination slightly; however, germination percentage for this treatment was about the same as that without $H_2O_2$ under the Clorox® lower temperature regimen. Because all scarification treatments were confounded with temperature settings in the dormancy-breaking experiment, the responses in terms of germination percentages cannot be separated by either scarification treatments or interactions between temperature settings and scarification.

Results of the experiment indicated there was dormancy in seeds from the Arctic, and it could be broken through various methods. It also demonstrated that a single dormancy-breaking treatment would be impractical for a mixture of seed from several species and genera. Even for this study, it would be unproductive to include seed dormancy-breaking treatments to reduce dormancy in our seed mixtures. Such treatments are time-consuming and may be impractical. For instance, by eliminating dormancy, all the seed applied is at risk of dying anytime growing conditions suddenly deteriorate before seedlings become well established. Also, it is possible that a dormancy-breaking treatment may shorten the life of seeds, allowing embryos to die

before seed could be transported from the laboratory to the field.

Dormancy was a factor affecting germination percentages and could not be easily quantified in germination tests for the overall study. Therefore, the germination percentages obtained without dormancy-breaking treatments were used to calculate seed application levels. Numbers of pure live seed (PLS) applied per gram were calculated from the germination percentage and the purity for each seedlot, i.e.,

$$\% \text{ PLS} = \% \text{ Germination} \times \% \text{ Purity}$$

This information was used, in combination with the number of seeds per gram, to calculate how many viable seeds were applied if a given mass of seed was planted to a unit area. For our seeded plots at the BP Put River No. 1 gravel pad, there were 2.97 $m^2$/plot, and each plot was 1/5 of each experimental unit on the gravel pad. Sixty-five PLS/$m^2$ was chosen as an arbitrary application in this experiment. For the 1990 planting, at least 2,885 PLS/$m^2$ were applied. With the site's capacity limited to supporting perhaps only 20 to 30 mature plants per $m^2$, it was obvious that these seeding applications were more than adequate, assuming all the PLS germinated. However, there are many chances for seeds to fail developing into mature plants.

The first two seed mixtures contained seed of 34 and 28 species, respectively, for the 1990 and 1991 plantings. Several of the collection seedlots were inadequate to provide 65 PLS/$m^2$ for each of the 144 experimental units and one row in the botanical garden. Therefore, computer spreadsheet formulas were used to calculate the application rates. Given the previously stated 65 PLS/$m^2$ goal for planting the 144 experimental units, the amount of total seed required was determined by the following formulas:

$$65 \text{ PLS}/m^2 \times 2.97 \ m^2/\text{Plot} = \text{PLS Number/Plot} = 193$$

$$193/(\text{Number of Seed/g}) = \text{Grams PLS Needed/Plot}$$

$$\text{Grams PLS Needed/Plot} \times 144 = \text{Total Grams PLS for Gravel Plots}$$

The amount of seed needed from each seedlot was compared with the amount of seed in the inventory. If there was an adequate supply in the inventory for the gravel plots and the botanical garden, we could use our preselected application of 65 PLS/$m^2$.

$$\text{Total Grams of Seed Required/144} = \text{Grams Seed to Weigh/Experimental Unit}$$

If there was insufficient seed to apply 65 PLS/$m^2$, a lower application was selected by trial and error, until the amount of seed in the inventory was adequate for the application and the botanical garden. This resulted in planting mixtures consisting of unequal applications of PLS/$m^2$ among various species in the mixture (Appendix E). For example, there was only enough seed of *Castilleja elegans* to apply 16 PLS/$m^2$ in the 1991 seeding (Table E-2, Appendix E). If seed from one species was harvested from two or more locations, the averages for germination and purity were prorated according to the proportional amount of seed in the planting mixture. This unequal seeding application limited the value of these tests for measuring interspecific competition, but it probably reflected actual conditions in nature. Seed production naturally varies among genera and species of plants among sites and among years. That variation provides unequal quantities of seed for natural colonization of barren sites.

Seeds were measured by weight, based on data obtained from the various laboratory procedures. Consequently, the exact amount of seed from each seedlot had to be weighed into 144 individual units, then added to each mixture. The collections of seeds spanned a large range of seed sizes, shapes, and surface characteristics (Figs. 11 and 12). It was impossible to maintain homogeneity of such a mixture while subdividing it. Therefore, the only sure method of maintaining consistent applications among seeded plots was to prepare individual mixtures of seed for each plot.

To prepare seed mixtures, two sets of jars were numbered consecutively from 1 to 144, one jar for each plot. The number on each pair of jars corresponded to one field plot. One set of jars was used to contain the combined seeds in the mixture for each experimental unit. The other set of jars was used to temporarily contain the aliquots from each seedlot from the time it was weighed until it was added to the mixture. The amount of seed for a given seedlot was weighed and placed into the temporary jars. After all 144 temporary jars had been allocated seed from a given seedlot, the seed was emptied from the temporary jars into the mixture jars. After all seedlots had been added to these mixtures, the mixture jars were capped and prepared for shipment to the field.

**Applying Seed Mixtures.** At the BP Put River

No. 1 site, 1.22 x 2.44 m plots were measured and staked at the corners. String was stretched along plot perimeters to delineate the area for planting. The surface of the gravel was raked to loosen the upper 2 to 4 cm of the substrate. To ensure an even application of the seed mixture throughout plots, the contents of each jar of seed were blended with about 0.5–0.75 liter of moist sand in a plastic bucket. This diluted the seed within a manageable matrix for the hand application and helped maintain a homogenous mixture during application. This seed/sand mixture was then distributed by hand throughout the plot as evenly as possible. Applying small amounts repeatedly across the planting area resulted in a relatively even distribution of seed. The plot was gently raked after applying the seed and tamped firmly to ensure maximum seed/soil contact (Fig. 13). Finally, the string was removed, but the stakes were left to delineate the area planted.

**Measuring Plant Responses.** Characteristics of plant communities developing on plots from the three seedings (those completed during 1990 and 1991, and the one proposed for 1993) with mixtures of native plant seed and the stands that form voluntarily on the unplanted portions of the plots are the indicators that will be used to measure the effects of the various gravel-fill manipulations. Types of data selected for this purpose were canopy cover, basal cover, species composition, plant vigor, height, and plant density by species. Only basal and canopy cover data for vegetation forming in the plots planted in 1990 and of unplanted plots in Replicate II were collected in September 1991.

Basal cover and canopy cover were measured using a point frame (Fig. 14). This device consisted of a metal frame with ten holes through which a metal rod was lowered to measure cover. Aerial contacts with plants were recorded as canopy cover, as were live plant leaves lying on the surface of the ground. Multiple contacts per sample point were possible for the canopy cover; however, only the first contact should be counted unless leave area index is desired.

Basal cover data consisted of records for pointer contacts at the ground surface. The basal cover categories were recorded as stem bases of live plants, stem bases of dead plants, rock, barren (soil or sand), mulch, moss, wood (debris), and animal feces. One basal cover datum was obtained for each hole in the frame. After all ten holes on the frame had been read, the frame was moved to another portion of the plot, and the process repeated. In each plot, three locations, i.e., 30 points, were randomly sampled.

The numbers of canopy and basal cover points per category were totalled on the data sheets and checked for accuracy and then entered into computer data files. The printed files were verified for accuracy by comparing with the field data sheets. These data files were summarized by blocks, replicates, and treatments: 1) gravel thickness (three levels), 2) topsoil (two levels), 3) tillage (two levels), 4) snow fence (two levels), and 5) seeded with grass (two levels) (Appendix F).

Samples of tissue were taken from four plots on 12 September 1991 to determine if nutrient deficiencies were affecting plant growth on these plots. Samples were clipped from Replicate III, Block 1 plots on the 0.6-m lift from tilled and untilled gravel plots and from tilled and untilled topsoil plots (Fig. 3). These samples were submitted to the Palmer laboratory for analyses of N, P, K, Ca, Mg, and Na.

**Photopoints.** Two sets of photopoints were established to record aspect changes of gravel vegetation plots over time. All 144 plots are included in both sets of photopoints.

The first photopoints are at the east end of each treatment, providing a view westward across the plots. The photographer stands at the east end of the plots back sufficiently to allow the entire east edge of the plot to span the lower camera view-frame. A 35-mm camera equipped with a 28-mm (wide-angle) lens is used, permitting all five subplots to be included in the photograph. The first photographs for this set of photopoints were obtained 23 July 1990.

The second set of photopoints is located at the west end of each experimental unit, providing an eastward view across the plots. The photographer stands on a stepladder, in order to include all subplots in the image and to give a less oblique view of the plots than obtained in the first set of photos. A 35-mm camera equipped with a 50-mm (normal) lens is used. The first photographs for this second set of photopoints were obtained 28–29 August 1991.

The east photopoints are located about 4.5 m from the western end of each of the experimental units (Fig. 15). A 35-mm camera with a 50-mm lens and Kodachrome® 64 transparency film was used. A 1.8-m step ladder was used to obtain the correct camera position and avoid including the snow fences in the photos. The view of experimental units was from west to east. It was framed horizontally, with the western end of the experimental unit at the bottom of the field of view such that the experimental unit extended com-

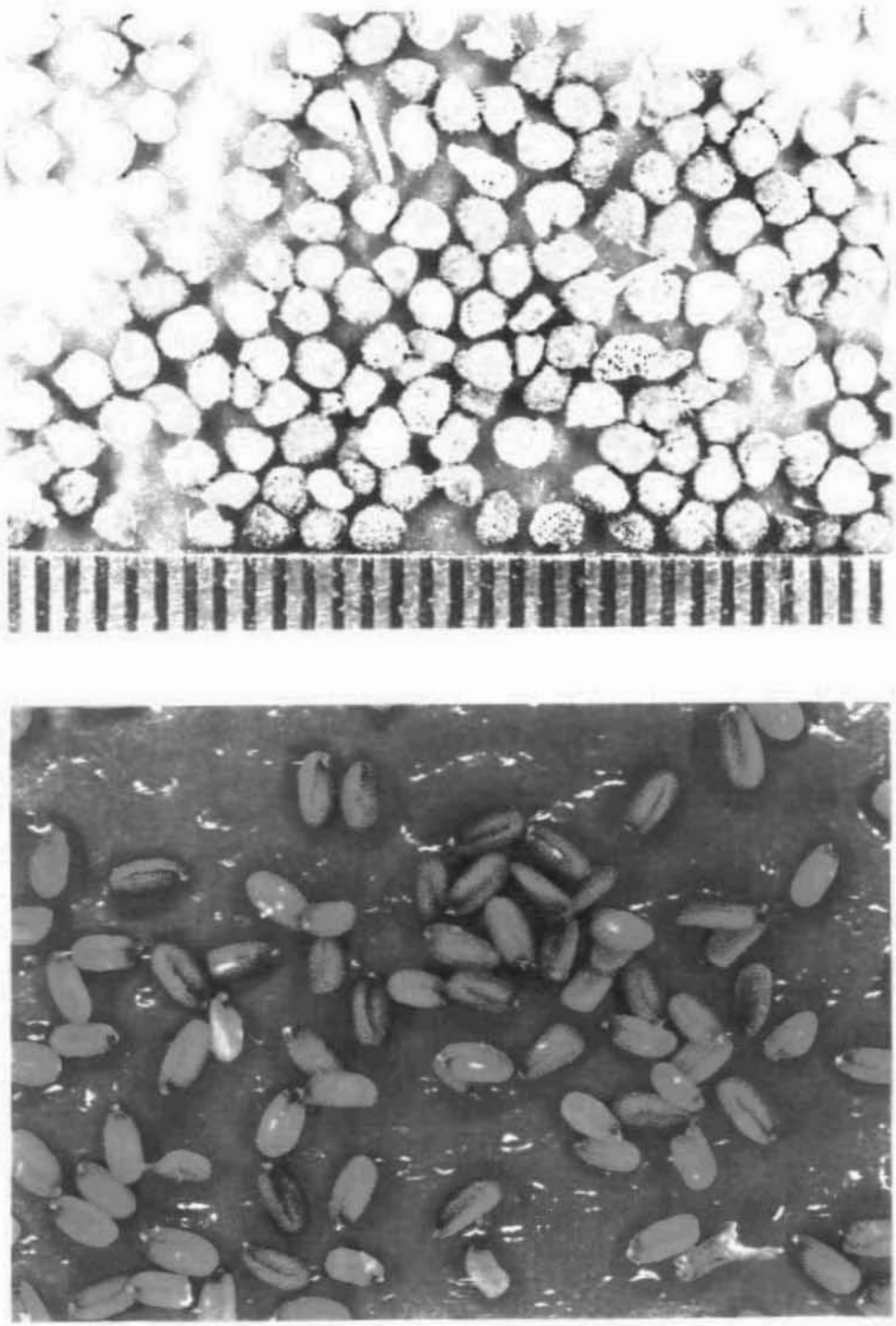

Figure 11. Rough seeds of *Cerastium beeringianum* (upper) and smooth seeds of *Arabis arenicola* (lower) from seedlots collected in 1990 on the Alaska North Slope.

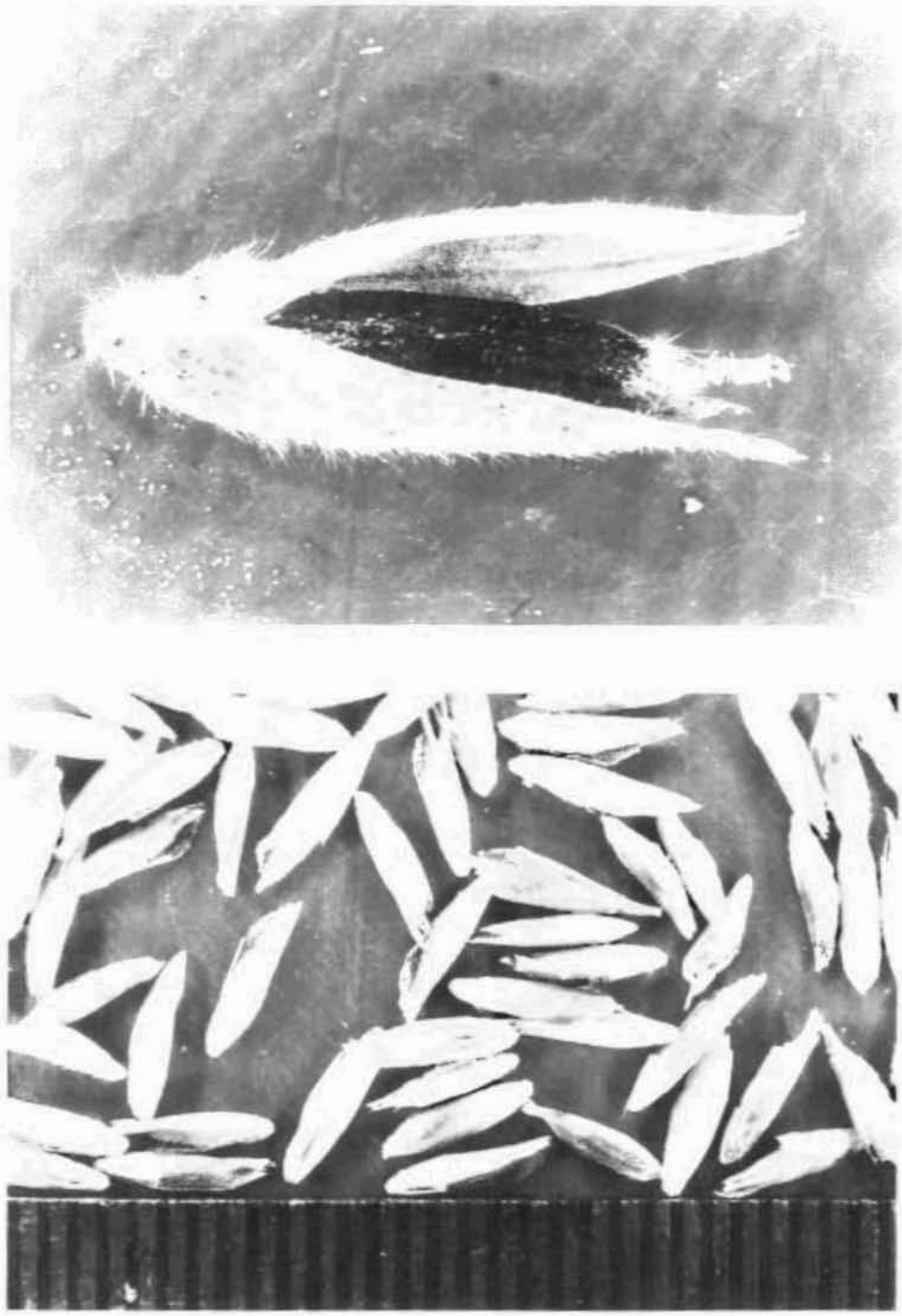

Figure 12. Exposed caryopsis (ovule) in *Elymus arenarius* (200 seeds/g) (upper) and smaller seed of *Puccinellia langeana* (6,400 seeds/g) (lower).

Figure 13. Tamping the surface of the seeded plots with rakes on the BP Put River No. 1 gravel pad (27 June 1991).

Figure 14. A point-frame was used to measure basal and canopy cover on gravel vegetation plots (4 September 1991).