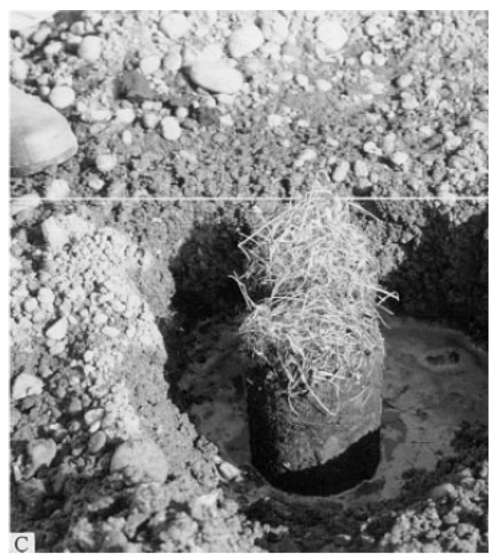
SOCIETY FOR ECOLOGICAL RESTORATION

USA: Alaska: The Role of Thermal Regime in Tundra Plant Community Restoration

Plugs were transplanted in August 1992; Credit: Shirazi et al. 1998



A single plug in July 1995; Credit: Shiraz

Overview

Mineral extraction activities in the Arctic regions of the world produce long-lasting ecological disturbances. Assisted recovery from such disturbances may require restoration of the tundra thermal regime. In this study, plugs of entire root zone and live tundra plants were transplanted to a disturbed site in Alaska oil fields. The dominant species were Carex aquatilis, Eriophorum angustifolium, Dupontia fisheri, Poa glauca, Festuca rubra, Salix ovalifolia, S. reticulata, and Sphagnum spp. The study focused on plant responses in the plugs to thermal regime manipulations by means of greenhouse and of single-or double-plug treatments. All plugs continued to produce new plants with time and expanded in area and canopy volume. Plants responded differently to treatments and generally reversed those responses when the greenhouse treatment was reversed the third year after transplant. This small-scale experiment showed that the native thermal regime of a plant community is vital in revegetating a disturbed tundra.

Quick Facts

Project Location:
Prudhoe Bay, AK, USA, 70.2556453, -148.33842930000003

Geographic Region:
North America

Country or Territory:
United States of America

Biome:
Tundra

Ecosystem:
Other/Mixed

Area being restored:
2.3 hectares

Organization Type:
University / Academic Institution

Location

(https://www.mapbox.com/)

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TIMEFRAME

Project Stage:
Completed

Start Date:
1992-08-02

End Date:
1996-08-02

DEFINING THE PROBLEM

Primary Causes of Degradation

Mining & Resource Extraction, Urbanization, Transportation & Industry

Degradation Description

The thermal regime of a permafrost system is defined by the rate of heat transfer between the atmosphere and the permafrost. The regime determines the thaw depth and the hydrology on the tundra. Gravel fills placed directly on the tundra for roads and structures associated with oil and gas operations alter this thermal regime. The fills may also directly block groundwater flow, thereby affecting the permafrost hydrology and thermal regime over extended areas. The physical effects of altered thermal regime, thaw depth, and permafrost hydrology are displayed on the tundra by surface subsidence. The biological effects are displayed in plant mortality, changing plant growth and reproduction, and shifting of the floristic composition of the tundra plant community (Lawson et al. 1978; Walker et al. 1987; Hinzman et al. 1996, 1997).

PLANNING AND DESIGN

Reference Ecosystem Description

The undisturbed tundra community used for donor transplant consisted of grasses, sedges, willows, and mosses. The dominant species in this community were Carex aquatilis (water sedge), Eriophorum angustifolium (tall cottongrass), Dupontia fisheri (Fisher's tundragrass), Poa glauca (glaucus bluegrass), Festuca rubra (red fescue), Salix ovalifolia (oval-leaf willow), S. reticulata (netleaf willow), and Sphagnum spp. (Kidd et al. 1996).

Project Goals

This project tested whether a live tundra plug, taken intact from a donor plant community with an attached root zone that had been cut to the depth of the thawed ground, could retain its own unique thermal regime on a small scale and, when transplanted in a disturbed environment with similar thaw and groundwater depths, if this living plug, with associated bacteria and mycorrhizae, would continue to grow and reproduce in that environment. The objective was to test this assumption with treatments that simulated varying rates of heat transfer to the transplants.

Monitoring

The project does not have a monitoring plan.

PROJECT ACTIVITIES

Description of Project Activities:

On 23 August 1992, two experimental plots were established, one on the gravel pad (henceforth the gravel plot) and a second on the native tundra (henceforth the donor plot) located approximately 220 m south of the gravel plot. Each measured 18.9 x 9.8 m. The donor plot was subdivided into 50 subplots 0.61 x 0.61 m in dimension arranged on a spacing pattern 1.83 x 1.83 m (center to center) comprised of five transects of 10 subplots each. On the donor plot, plugs 13.3 cm in diameter were cut to the depth of the active layer (15 - 30 cm) with a core-cutting tool of our own design. When the cutting edge of the tool reached the bottom of the active layer, the plug sheared at the frozen boundary and was easily lifted, intact, with the cutting tool. A total of 60 intact plugs were extracted from the donor plot and the holes filled with substrates from the gravel plot to test the effect of changing substrate thermal conductivity in the donor plot. The experimental gravel plot at NPBS2 measured 22.6 x 9.7 m and was part of a larger area that was fertilized in 1992 with 20-20-10 NPK mixture, 450 kg/ha, and left for "natural" recovery (Kidd et al. 1996). The gravel plot was subdivided into 60 experimental subplots of 1.8 x 1.8 m spacing (center to center) arranged in five transects of 12 subplots each. Four treatments were applied to subplots on the gravel plot: ambient or exposed single plug transplant, exposed double-plug transplant, a single plug covered with a greenhouse, and double plugs covered with a greenhouse. Treatments were randomly assigned to each subplot, and 10 replicates of each plug treatment were installed. Tundra plugs were transplanted in the gravel plot by excavating a small hole equal in depth to the length of the plug to be planted. Double plugs and single plugs were used to vary the belowground tundra sod volume and heat transfer rates. Double plugs were transplanted adjacent to one another, touching on a side with no space between them. Ten single plugs and 10 double plugs were covered on 10 June 1993 with commercial polyethylene storage totes (greenhouses), slightly tapered toward the base and measuring 54 x 39 cm at the open end. When inverted, the tapered top of these "greenhouses" was 31 cm above ground. Other planted plugs were left exposed. Air and soil temperatures from one ambient reference station without a greenhouse and two treatment stations with greenhouses were collected from 10 June through 30 August 1993. The thermal regime of covered plugs was subjected to a yearly cycle as a result of applying the greenhouse year-round. Both study sites were visited on 14 - 17 July 1993, 29 August - 3 September 1993; 10 - 15 August 1994, 17 - 22 July 1995, and 11 - 13 August 1996. Plant responses in the gravel plot and donor plot were monitored during each visit by counting the live shoots of sedge, grass, and willow, and by measuring plug area, moss cover, and willow cover. The canopy volume over each plug was measured by multiplying the mean height and plug area. The canopy volume for the donor plot was the initial plug area multiplied by the mean canopy height in the donor plot. During the July 1995 visit, many greenhouses were found filled to near capacity with new growth. All greenhouses were removed from treated plugs and placed on the exposed plugs to initiate a new phase of thermal-regime manipulation. During the August 1996 visit, however, only 3 out of 20 boxes were found in place; the remaining boxes were broken or removed from the plugs by unknown agents, apparently during the early spring of that year. Plant responses for that year were collected, and the results reflected mixed or "reversed" treatments. The responses of several plant species were grouped together rather than studied intensively. For example, the responses of Carex aquatilis, Eriophorum angustifolium, E. Russeolum (red cottongrass), and other sedges were reported under sedges; Dupontia fisheri, Poa glauca, Festuca rubra, and other grasses were reported under grasses; and Salix ovalifolia, S. Reticulata, and Salix spp. were reported under willows. The plant responses from the gravel plot and the donor plot were used in analyses of variance. Comparisons of mean plant responses from the gravel plot with those from the donor plot were conducted by Dunnett's mean separation test to estimate the joint confidence factors (Dunnett 1955; Becket et al. 1988).

PROJECT OUTCOMES

Ecological Outcomes Achieved

Eliminate existing threats to the ecosystem:

--Air and Soil Temperatures-- During the first growing season, the cumulative greenhouse air and soil temperatures were 749Â° and 628Â°C thawing degree-days. The ambient air and soil temperatures during the same period were, respectively, 444Â° and 566Â°C thawing degree-days. The mean greenhouse air and soil temperatures were 9.3Â° and 7.8Â°C, while the mean ambient air and soil temperatures were 5.5Â° and 7.0Â°C, respectively. --Plug Holes in the Donor Plot-- The surfaces of the filled holes in the donor plot remained bare and sank below the tundra grade at a rate of 1 - 2 cm/yr. --Sedge-- Mean sedge densities increased with time. Mean densities for the donor, July 1995, and August 1996 treatments were, 882, 1186, and 1329 treatments/m2. The sedge density continued to increase after greenhouse reversal. The mean sedge densities for single exposed, double exposed, single covered, and double covered plugs for July 1995 were 1460.0, 1483.0, 720.7, and 1080.0 treatments/m2 and for August 1996 were 1520.0, 1362.0, 1137.0, and 1297.0 treatments/m2, respectively. The sedge density was higher for exposed plugs than covered plugs; reversing the greenhouse treatment accordingly reversed the response. Covering the double plugs reduced sedge density more than covering the single plugs. --Grass-- Mean grass densities generally increased with time. Mean densities for the donor, July 1995, and August 1996 treatments were, respectively, 33.7, 304.2, and 353.0 treatments/m2. The grass density continued to increase after greenhouse reversal. Mean grass densities for single exposed, double exposed, single covered, and double covered plugs for July 1995 were 338.3, 319.2, 254.6, and 304.5 treatments/m2 and for August 1996 were 469.9, 387.6, 216.0, and 342.1 treatments/m2, respectively. Grass density was higher for exposed plugs than covered plugs; reversing the greenhouse treatment did not reverse the response except for single covered plugs. Other treatments were dominated by continued increasing grass densities. --Willow-- Mean willow densities generally decreased with time. Mean densities for the donor, July 1995, and August 1996 treatments were, respectively, 235.3, 105.1, and 89.4 treatments/m2. Willow density continued to decrease after greenhouse reversal. Mean willow densities for single exposed, double exposed, single covered, and double covered plugs for July 1995 were 80.4, 109.5, 80.8, and 149.8 treatments/m2 and for August 1996 were 53.5, 86.7, 83.0, and 134.4 treatments/m2, respectively. Willow density was higher for covered plugs than exposed plugs; the effect of reversing the greenhouse treatment was dominated by the continued decline in willow densities in all but the single covered plugs. --Willow Cover-- Mean willow cover decreased in the second year but continued to increase thereafter. Mean willow cover for the donor, July 1995, and August 1996 treatments was, respectively, 17.7, 12.2, and 14.0%. Mean willow covers for single exposed, double exposed, single covered, and double covered plugs for July 1995 were 4.36, 3.73, 11.40, and 29.4% and for August 1996 were 10.9, 7.73, 16.1, and 21.2%. Therefore, greenhouse treatments before and after reversal increased willow cover in single and double plugs even while their willow density decreased relative to that of the donor plugs. --Moss-- Mean moss cover decreased the second year but increased thereafter. Mean moss cover for the donor, July 1995, and August 1996 treatments was, respectively, 53.3, 35.0, and 28.1% Mean moss cover for single exposed, double exposed, single covered, and double covered plugs for July 1995 was 14.6, 26.82, 60.0, and 38.6% and for August 1996 was 46.8, 28.9, 26.0, and 10.6%, respectively. This shows that exposed plugs produced greater moss cover than covered plugs and that reversal of the greenhouse treatment accordingly reversed moss cover. --Plug Area-- The plug area that was initially 140 cm2 was also assumed as a reference plant area for the donor plot. The plug area in 1993 was assessed by visual inspection to be unchanged. Mean plug area increased with time. Mean plug areas for July 1995 and August 1996 treatments were, respectively, 373 and 4528 cm2. Plug area continued to increase after greenhouse reversal. Mean plug area for single exposed, double exposed, single covered, and double covered plugs for July 1995 was 285, 243, 571 and 395 cm2 and for August 1996 was 407, 311, 565, and 428 cm2. This shows that plug area increased with greenhouse treatment and that the reversal did not reduce the areas previously gained by the covered plugs. --Canopy Volume-- Mean canopy volume for the donor, July 1995, and August 1996 treatments was 1.15, 8.02 and 7.36, respectively. Mean canopy volume for single exposed, double exposed, single covered, and double covered plugs for July 1995 was 2.88, 2.52, 15.4, and 11.3 and for August 1996 was 5.69, 4.47, 10.9, and 8.39. Canopy volume increased with greenhouse treatment; reversal reduced the mean canopy height previously gained by the covered plugs. --Summary of Results-- Grass density and canopy volume were consistently highly significant responses to thermal manipulation in July 1993 and August 1994. Plug area in 1994 was highly significant. Sedge density in 1993 and sedge density and willow densities in 1994 were not significant. Plant responses to greenhouse and plug number treatments for 1995 and 1996 were highly significant in all but willow density in 1995, willow cover in 1996, and moss cover in 1995 and 1996. Plants displayed complex response patterns to treatments.

Socio-Economic & Community Outcomes Achieved

KEY LESSONS LEARNED

Key Lessons Learned

This study did not verify reestablishment of the native thermal regime by direct heat balance measurements from the permafrost through the plant canopies in the donor and gravel plots. Conducting such measurements is extremely difficult. The gravel plot and the native tundra plots have vastly different thermal properties that contribute to different modes of heat transfer and seasonal and annual thermal regimes. For example, the mean thermal conductivity of the top 20-cm layer of the gravel is seven times greater than the top 50 cm of the tundra; the rates of heat transfer by convection, evapotranspiration, and conduction in undisturbed tussock tundra during early June are 8%, 58%, and 33%, respectively, and during early July are 47%, 32%, and 21%, respectively (Hinzman et al. 1996, 1997).

Having no direct measurements, it was not possible determine the degree to which a native thermal regime might have been established in the transplanted plugs. Instead, statistical inference based on the analysis of plant response to experimental manipulation of the thermal regime was used to determine whether some degree of native thermal regime was attained and plants survived or whether no degree of native thermal regime was attained and plants did not survive as a consequence of these manipulations.

The outcome of these manipulations was integrated in the measured plant responses. Analysis of variance tests was used to confirm that thermal-regime manipulations had highly significant effects on these observed plant responses. Sedges, grasses, willows, and mosses in the plugs generally responded differently to greenhouse and plug number treatments, and they generally produced reversed responses upon the reversal of greenhouse treatment. Whereas plants responded in a complex and diverse way to these manipulations, plug area and canopy volume continued to increase with time. Hence, the range of thermal-regime manipulation experienced by plugs in the gravel environment more or less corresponded to the native thermal regime.

The primary concern with respect to establishing a near-native thermal regime of transplanted plugs was the influence of the gravel environment on the small volume of the plug. But the plug hole experiment in the donor plot demonstrated that the thermal regime operated on a very small scale""that is, on the scale of the transplanted plug volume. The sinking of the gravel in the hole was the direct consequence of the difference between the thermal regime of the filled hole and that of live tundra plants surrounding the hole. This experiment explained how transplanted plugs may partially retain their native thermal regimes on the scale of single or double plug volumes, particularly that evapo-transpiration in summer

(Hinzman et al. 1996, 1997) was an important component of this regime and that the hydrology of the gravel environment was similar to the native hydrology. The moisture regime of the plug was simulated to near donor plant conditions by cutting the plugs deep enough to reach the groundwater during June and August throughout the gravel plot and during July in the western section of the gravel plot when the groundwater level dropped to its lowest level. These levels were monitored by Kidd et al. (1996) at two stations across the northern section of the gravel plot.

In the gravel plot, plants in the plugs grew new green tissues, shoots, roots, tillers, seedheads, and litters. That all the 60 transplanted plugs in the gravel plot survived and produced new plants, and that the reversal of greenhouse treatment generally reversed the plant response, demonstrate that the manipulations were not so extreme as to cause irreversible plant response but were within the tolerance of plants in the plugs.

Irreversible effects of thermal regime have also been reported in plug transplants. For example, Jorgenson and Cater (1991) and Kidd et al. (1996) used tundra plug transplants with a primary focus on revegetation. Plugs were cut by spade and post-hole diggers, which produced shallower plugs and smaller mat volume than the ones used in this study. Jorgenson and Cater (1991) transplanted tundra plugs on a 1.5-m-deep gravel pad, and Kidd et al. (1996) transplanted more than 2000 plugs into 0-30 cm deep water in a NPBS2 gravel pad outside the gravel plot described in this study. The plugs were taken from undisturbed donor sites similar to those of this study.

The plugs in the deep gravel plot produced 11% total cover in one growing season (Jorgenson & Cater, 1991), compared with 95% total cover in the exposed plugs after one growing season in this study. The plugs in water experienced 58% mortality and produced 3% cover after three growing seasons (Kidd et al. 1996), compared with 235% and 189% increases, respectively, in canopy volume and plug area in the exposed plugs after three growing seasons in this study. These two studies provide useful contrasting examples of hydrologic host environments of transplants, one because of inadequate moisture in the deep gravel and the second because of excess moisture. The examples confirm the need for matching the thermal regimes of transplants and the host environment.

LONG-TERM MANAGEMENT

Long-Term Management

Restoration of wetlands is a requirement under Section 404(b)(1) of the Clean Water Act for issuing a permit in Alaskan oil fields. The current restoration approach has a strong focus on revegetation to produce plant cover by methods that include direct seeding, fertilizing, sludge amendment, mulching, grass transplants, plug transplants, moisture enhancement with berms, and long-term studies of plant succession. Unfortunately, in these efforts, the components of heat transfer rates that determine a stable thermal regime of the restored tundra community have not been taken into account (Jorgenson & Cater 1993; Herlugson et al. 1996; McKendrick 1991, 1997). This study, therefore, has important implications for the restoration of disturbed tundra sites because it stresses the importance of a previously overlooked facet of restoration and will potentially influence practice going forward.

Indeed, the results of this study suggest that revegetation techniques that promote stabilization of the thermal regime may accelerate recovery. In 1988 the Kuparuck Oil Fields contained 472 ha of fill for roads and pads. Mining for gravel produced 239 ha of mine sites and an equal area for stockpiling mine refuse (Jacobs et al. 1993). Therefore, for every hectare of gravel fill, 2 ha of tundra mat are available at the design stage; but advance planning and engineering must be in place for its use in restoration. Knowledge of the permafrost thermal regime is a necessary requirement not only for oil exploration and production, for building stable and safe roads, and for establishing sound supporting structures for equipment and pipelines; but it is also needed for the restoration of tundra communities. The two objectives can be integrated so that adequate planning is in place for maintaining and using live tundra mats that at present are inevitably destroyed under gravel fills and mine-site stockpiles.

FUNDING

Sources and Amounts of Funding

This project was conducted with funding from the EPA, through its Office of Research and Development.

LEARN MORE

Other Resources

Shirazi, M.A., P.K. Haggerty, C.W. Hendricks, and M. Reporter. 1998. The role of thermal regime in tundra plant community restoration. Restoration Ecology 6(1):111-117.

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