Physical Environment

The Arctic National Wildlife Refuge spans 9.6 million acres and lies on the edge of the Artic Ocean and, bordered by Prudhoe Bay to the West and the Canada to the East. The 1002 area, 1.5 million acres of northeastern ANWR, lies on the Coastal Plain of ANWR and is situated in the 100 miles between the Aichilik River to the east at 142º 10' W and the Canning River to the west at 146º 15' W. It is trapped between the Brooks Range Mountains located at 69º 35' N and the Beaufort Sea at 0º 10' N, and its close proximity to the two ecoregions produces a variety of ecological conditions and habitats which support a wide spectrum of vegetation.

The entirety of ANWR spans many regions, including the Arctic coast, the tundra plain, the Brooks Range Mountains, and the Yukon basin forests. It contains over 20 rivers, including National Wild Rivers the Sheenjek, Ivishak, and Wind; North America's largest and most northerly alpine lakes Peters and Schrader; warm springs; lagoons; and glaciers. In the 1002 area, specifically, there are also many rivers that run northward and a few large lakes which freeze all the way to their bottoms by winter. Polygonal patterns on the ground across the region are formed by the seasonal thawing of the surface which will be explained in greater detail in the hydrology section. The disturbance of the surface tundra results in permanent alteration of the terrain, including the creation of ponds, ice wedges, vegetative cover and erosion.

[Climate]
[Hydrology]
[Soil]
[Soil Microbial Processes]
[Nutrient Cycles]

Physical Environment - Climate

The climate of Northern Alaska can be divided onto three different zones: Arctic Coastal, Arctic Inland and Arctic Foothills. Extending 20 km from the ocean, the 1002 area falls under the category of Arctic Coastal, which is characterized by cool summers and relatively warm winters, due to the impact of the ocean. Partially due to the rain shadow created by the Brooks Range just south of the coastal plain, the region has the lowest precipitation, 50 percent of which falls as snow. The air temperatures remain below freezing through most of the year and snow covers the ground surface for more than 8 months from October through April (Zhang, Osterkamp 1996).

Temperatures

Temperatures reach a high of about 86 degrees F in the summer (averaging about 41 degrees) yet drops to well below zero (averaging -4 degrees) in the winter. The global warming trend has already increased temperatures in the Arctic by 5 degrees F and 8 degrees in the winter since the 1960s, leading to shorter ice seasons, glacier melting, permafrost thaw, and increased precipitation. The inevitable change in climate may lengthen the growing season, but it will also alter the delicate ecological balance in ANWR (anwr.org).

Precipitation

Measuring precipitation in a wind-swept region, especially where the total quantity is small and more than 50 percent comes as snow, is a complicated problem. ANWR has an average rainfall of about 25cm, and solid winter precipitation for coastal areas averaged 15.3cm for the three years of study 1994-97. Out of this 34 percent of the precipitation sublimed (Sturm 2002).

During the winter months, virtually all precipitation falls in solid form. The low-growing vegetation and high wind speeds that characterize the domain allow significant wind redistribution of snow throughout the winter. This means that snow depths can be quite variable and, under appropriate conditions, some of the snow cover is returned to the atmosphere by blowing snow sublimation. Winter precipitation measurements do not exist in wind-blown arctic regions (Sturm 2002).

Snow cover

Snow cover possesses certain thermal properties which compete with air temperature on the ground thermal regime. It has high reflectivity and emissivity that cool the snow's surface; snow cover is a good insulator that insulates the ground; and melting snow is a heat sink, owing to its latent heat of fusion (Zhang et al., 1997). In spite of the high albedo from spring and early summer snow and cloud cover, net radiation is positive throughout the year (Hare, F. K. 1972).

The microclimate of an environment, or the climate near the ground, is largely a function of energy exchange phenomena at the ground-air interface. The average maximum thickness of the seasonal snow cover varied from about 30cm along the Arctic coast to about 40cm inland for the period from 1977 through 1988 (Zhang et al., 1996a). The thickness of seasonal snow cover, however, can vary substantially on a micro scale due to the impact of wind, ground surface morphology, and vegetation. Along the Arctic Coastal Plain, the ground surface is relatively flat and mainly occupied by low-center polygons. Vegetation is poorly developed, and the region experiences high wind speeds during the winter months (Haugen 1982).

In this setting, the snow can be either blown away or well packed by strong wind, reducing the insulating effect. Inland, the ground surface becomes rough and vegetation changes significantly as a result of increased summer warmth. Wind redistributes the snow which is better trapped in the troughs and depressions created by rough micro relief and the taller vegetation. The trapped snow increases the insulating effect of the seasonal snow cover, which, in turn, influences the permafrost conditions that determine vegetation of the area. On a monthly basis, seasonal snow cover warms the ground surface during winter months but cools it during the period of snowmelt. On an annual basis the seasonal snow cover definitely warms the ground surface. (Zhang et al., 1997)

In contrast with the Arctic coast, the Arctic inland and Arctic foothills feature lower wind speed, a very rough surface with tussocks, troughs and depressions, and well-developed vegetation. Snow can be interrupted and trapped by vegetation and rough surface, increasing the insulating effect and permafrost temperatures.

Effects of Global Warming

Climatic warming associated with elevated levels of greenhouse gases in the atmosphere is predicted to be greater in the Arctic than elsewhere, almost two to three times more than the global average (Osterkamp 1982). The impact of climatic warming on the Arctic ecosystem is uncertain, as are the feedback processes to potential changes in the exchange of greenhouse gases between the polar soil and atmosphere. This will be discussed further with relation to soil and the carbon cycle. One of the main reasons is that climatic conditions on the north slope of Alaska are not well understood owing to the sparsity of meteorological stations and discontinuity of observations.

Analyses of data collected by a number of studies done from the late 1940s onwards at and around Barrow and Prudhoe Bay showed that the permafrost surface has warmed 2º to 4º C in the Alaskan Arctic over the last century (Lachenbruch and Marshall 1986; Lachenbruch et al., 1988). Since then, the rate of increase in temperature has accelerated greatly, to about 1º C per decade. Snow and shrubs form a positive feedback loop that could change land surface processes in the Arctic. The increased subnivian soil temperatures that are observed would produce conditions favorable to shrub growth (i.e. more decomposition and nutrient mineralization) (Strum et al., 2001). Aerial photographs taken of Alaska's North Slope during the 1940s offer some of the best evidence of such change: a dramatic increase in the growth of trees and shrubs in the Arctic.

Physical Environment - Hydrology

Water Availability

The Arctic Coastal Plain may seem to be abundant in water resources. In actuality however, the low precipitation limits the amount of readily available water. Most of the available water resources come from snow melt, runoff, rivers, and lakes within the area. In arctic and subarctic areas, rivers typically carry 55 to 65 percent of precipitation falling onto their watersheds. The reason for that is that the permafrost prevents the downward percolation of water and forces it to run off at (and very near) the ground surface. Consequences of the high runoff include the fact that northern streams are much more prone to flooding and that they have higher eroding and silt-carrying capabilities (Bowling et al., 1997).

Critical to the control of water runoff in the north is the cover of moss and other vegetation of the tundra, bogs and forests. A thick layer of moss acts much like a sponge lay over the permafrost to slow down the movement of water across the ground surface.

Frozen Water Formations

One primary source of water is in thermokarsts or thaw lakes. These lakes are actually thaw basins: low areas in the tundra where water from melting snow and ice collects. Thousands of square miles in the Arctic are covered by ground which has been segmented into what are called tundra polygons or ice wedge polygons. This pattern is caused by intersecting honeycomb networks of shallow troughs underlain by more or less vertical ice wedges. The ice wedges are formed when the ground contracts and splits in a manner analogous to the formation of cracks on the dry lake bed. This allows water to enter, and successive seasons of repeated partial thawing, injection of water, and refreezing cause the wedges to grow. As they grow, the strata to either side turn up to enclose the polygon, and a lake may form in the center with the raised troughs at the margins. Above the frozen region, unfrozen water saturation increases due to low hydraulic conductivity, which prevents the melting ice from draining, thus causing accumulation of water above it (Panday and Corapcioglu, 1995). During this process, pingos are sometimes formed when the pressure from the contraction of the unfrozen water pushes it up until it collects and freezes under the root mat.

All of the thaw lakes studied were very shallow; even though the lakes could be several thousand feet long, most were no deeper than 10 feet (Bowling et al., 1997).

Drainage patterns typically follow the troughs, and where they meet, small pools may form. These are often joined by a stream which causes the pools to resemble beads on a string - in fact, this type of stream form is called beaded drainage. Thaw lakes tend to be elongated perpendicular to prevailing winds caused by subsurface currents. The waves caused by crosswinds may be eating away at the peat more aggressively along the edges creating a pattern of elongation that all arctic lakes share(Bowling et al., 1997).

The amount of available water in the 1002 area has been estimated to be around 9 billion gallons.

Water Usage in the 1002 Area

Water resources are limited in the 1002 Area. In winter, only about nine million gallons of liquid water may be available in the entire 1002 Area, which is enough to freeze into and maintain only 10 miles of ice roads. Although such exploration is conducted only in winter, snow cover on the 1002 Area is often shallow and uneven, providing little protection for sensitive tundra vegetation and soils. The impact from seismic vehicles and lines depends on the type of vegetation, texture and ice content of the soil, the surface shape, snow depth, and type of vehicle.

Oil companies are withdrawing surface water faster than it can be replenished, says Steve Lyons, hydrologist with the U.S. Fish and Wildlife Service (USFWS). When an ice road melts, the water runs over the surface into streams, usually outside the original watershed from which it was withdrawn, he explains. Because the 1000-ft-thick permafrost does not allow groundwater movement between water bodies, lakes are filled only by snowmelt and may take more than two years to refill after the permitted 15% of their liquid volume is withdrawn for ice road construction (Pelley, 2001).

Surface water will also be used for potable purposes at manned facilities, equipment washing, tank cleaning, dust abatement on roads and workpads, and hydrostatic testing.

Permafrost

Examining the soil and water cycles of the 1002 region, one cannot ignore the presence of permafrost, or "permanently frozen soil," which underlies 80% of Alaska and remains a central issue in the debate about oil drilling. Permafrost has been defined as frozen ground in which a naturally occurring temperature below 0° C (32° F) has existed for two or more years (Bowling et al. 1997). On the North Slope, permafrost ranges in thickness from about 700 to as much as 2,240 feet thick, and may be as cold as -8° to -10° C.

Permafrost can be either thaw-stable or non thaw-stable, depending on the type and percentage water of the soil it is made of. Permafrost in more fine-grained soils like loess (silty) tend to thaw, sink, and create thermokarsts more often. Permafrost thaws from heat input, such as global warming or human activity, as well as the clearing of vegetation which insulates the ground.

Permafrost is affected by road dust generated by traffic on unpaved roads; snow melt due to dust deposition can lead to flooding, ponding, and hydrological changes in oil. Continuing oil and gas exploration, development, and production, construction of a natural gas pipeline, the operation and maintenance of facilities, and other activities requiring road travel would add cumulatively to the volume of road dust generated on unpaved roads (BEST, PRB, 2003). Regions of ice which have been wind-dusted are likely to undergo localized melting earlier than the neighboring non-dusted ice (Bowling et al. 1997).

There are three approaches to dealing with the permafrost problem in the construction practice. The first and most obvious is to avoid it entirely. The second is to destroy it by stripping the insulating vegetative cover and allowing it to melt over a period of years. This has the obvious drawback of requiring a considerable period of time to elapse before construction can begin, and even then, it is a good idea to excavate the thawed ground and replace it with coarse material.

The third approach, and one which is becoming more widespread, is to preserve it. This can be accomplished by building on piles to allow cold air to circulate beneath heated structures, by building up the construction site with gravel fill which insulates and protects the permafrost below, or by refrigeration to maintain low ground temperatures. This is done by utilizing thermal piles or freeze tubes, such as those used by the trans-Alaska pipeline. These devices are filled with a non-freezing liquid and act like coffee percolators. They are cooled during the winter months and draw heat from the ground to retard thawing during warm weather (Bowling et al. 1997).

In nearshore areas, ice-bonded permafrost is probably present and must be considered in the design of an offshore pipeline. But nearshore ice-wedge permafrost under shallow water, particularly along a rapidly receding coastline, is even more critical for design. Oil pipelines placed in areas of ice-bonded or ice-wedge permafrost must be heavily insulated to limit thawing of permafrost. The best location for an offshore platform is at water depths of 6.5-65 feet, to minimize ice gouging. Beyond the 6.5 foot water depth the top of the ice-bonded permafrost generally is below the surface of the seabed. Inshore of the 18-foot bottom-depth contour, ice gouging is typically less than 1.6 feet (Kutasov, 1997).

Important aspects of disturbance and recovery in permafrost regions

The physical system

Ice-rich permafrost is a major factor controlling disturbance and recovery in the Arctic. If the permafrost thaws, thermokarst can be initiated on a large scale, and a critical point is reached where it is difficult or impossible to return the site to its original state within a few decades because of continued subsidence (Walker)

Thawing of ice causes:

- hydrologic changes(impoundment of water or creation of flowing water
- thermal changes by decreasing the albedo of the surface and increasing heat flux to the site
- geochemical changes(usually increased nutrient availability)

Attributes that contribute to thermokarst

- volume of ground ice in the near surface sediments
- steepness of the terrain
- grain size of the sediments

Disturbance in areas with high amounts of ice, rolling topography, and fine-grained sediments may not stabilize even 30 years after the disturbance. Grain size and steepness can be determined from surficial geology maps and digital terrain models(DTMs)

Overall oil production and industrial activity will melt permafrost, affecting plant growth in the area.

The thawing of ground ice causes hydrologic changes due to the impoundment of water or creation of flowing water. There are also thermal changes by decreasing the albedo of the surface and increasing heat flux to the site. Geochemical changes is usually in the form of increased availability of nutrients. All of these have serious implications on the entire ecosystem. Therefore, it is not without reason that scientists have formulated the following:

The fragility of tundra to destruction is directly proportional to the ice content of the permafrost and inversely proportional to the mean ground temperature (Arctic and Alpine Vegetations: Similarities, Differences, and Susceptibility to Disturbance, Billings).

Modification of the site following disturbance

If heat flux to ice-rich terrain is increased, such as by changes in surface albedo, hydrologic conditions, thermal conductivity of the active layer, snow regime, or local sources of heat(eg. from drilling machinery or hot oil) thermokarst might likely result. The control on heat flux are complex. The radiation balance and thermal properties of the soil are affected by position, depth of the moss carpet, bulk density of the soil, vegetation cover, snow cover, and moisture regimes. Deep organic layers and thick moss carpets are good insulators against heat flux unless the organic material is saturated, as is often the case in low microsites. Physically based models of heat flux now offer predictions of changes to annual thaw depth in response to climate change. The time required for vegetation recovery and the type of vegetation that will reoccupy the site is also controlled by the thermal stability of the site. (Walker 1991).

Relation of oil drilling, permafrost and vegetation

Permafrost layer restricts the drainage of water through the soil, making it moist in the short summer growing season. It is easily broken by road construction or the seismic explosions used in oil exploration, changing the water drainage patterns of the soil and thus retention of moisture. Melting permafrost has also led to widespread damage of buildings, costly road repairs, and increased maintenance for pipelines and other infrastructure impacts that will continue to grow in magnitude. Permafrost also stores large amount of ancient carbon and methane; thawing is likely to release some of this stored carbon and methane back into the atmosphere, amplifying the risk of further climate change. The boreal forest will advance northward into present coastal plain tundra, and mixed forest into present boreal forest. Forest fires and insect outbreaks, both of which have increased sharply in recent years, will further increase. If the permafrost thaws, the vegetation will in the long term dries out, altering plant communities and use by wildlife.

It has been observed that in areas where the permafrost thaws, there is a sudden rapid growth of plants, which attract more animals to feed on. However, this is only momentary. Once the permafrost thaws, temporarily there is much water for plants to grow well for like a month or two, but then the water is continuously used up and drained away as there is no layer to prevention drainage now; yet the permafrost, once destroyed, take years to resume. Therefore, a few months after destruction, water will finally be deficient and no plants can grow well even during summer when water has already been used up, drained away but no permafrost exists to trap them for the growing season. This detrimental effect on vegetation is permanent, while the vast growth of plants is just transient.

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Physical Environment - Soil

The Arctic Coastal Plain consists of marine (carried into seas by streams and beach erosion), fluvial (carried by flowing river water), alluvial (carried by river water that gradually loses velocity), and aeolian (carried by wind) deposits from the rising of the Arctic Sea on the plain in the mid/late Quaternary Age.

The Coastal Plain is dominated by lakes and poorly-drained soils, while the Brooks Range has less lakes and more well-drained soils (due to river flow). Poorly-drained soils mostly result from the predominance of permafrost, which restricts water flow in and out of soil, as well as impermeable bedrock in more upland areas.

Active Layer

During the short summers, the active soil layers above the permafrost table thaws briefly to depths of 20-75 cm and allows root penetration, growth and nutrient uptake by the tundra vegetation.

Soil Types of the Area

- Pergelic Cryaquepts: low-lying, seasonally flooded, shallow surface mat of partially decomposed organic matter grading into dark gray sandy loam.
- Histic Pergelic Cryaquepts: lowlands, slightly to moderately decomposed organic matter grading into dark green-gray silt loam.
- Pergelic Cryofibrists: poorly-drained, organic, made of thick layer of sedge and moss peat.
- Typic Cryochrepts/ Alfic Cryochrepts/ Aeric Cryochrepts

"Histic" indicates that the soil is shallow with poorly aerated organic material; "Pergelic" refers to temperature "regime," indicating the presence of permafrost; and "Aquept" suggests poor drainage. The soils of the 1002 region are generally loamy, gravelly, and from nearly level to hilly/steep association.

Vegetation vs. Soil

Site	Dominant Vegetation	Soil Suborder	Max thaw depth (m)	pH
Tussock Tundra	Eriophorum Dwarf Shrubs Sphagnum	Pergelic Histic Cryaquept	.4	6.4
Heath	Dryas Betula Salix Ericads	Pergelic Ruptic Entic Cryumbrept	2-5+	4.2
Shrub-Lupine	Salix Cassiope Lupinus	Pergelic Histic Cryaquept	1-2+	6.9
Equisetum	Lupinus Grasses, Sedges Equisetum	Pergelic Histic Cryaquept	.45	7.4
Wet sedge	Carex Eriophorum	Pergelic Cryohemist	.55	6.6
Willow	Salix Betula Lupinus Sphagnum	Pergelic Cryofluvent	+	7.8

(Valentine 1992)

pH

The soil pH ranges from approximately 4-8, depending on the soil type, topography, and amount of disturbance to which it was subject. High weathering and cryoturbation generally makes the soil less acidic, introducing more basic materials to the soil matrix. Frost boils, on the other hand, lowered the pH by moving the organic layer deeper in the soil and increasing the depth of thaw. The pH of the soil has a clear relation to the species diversity and density within the area. (Valentine 1992)

Element/Nutrient Composition and the Issue of Heat

Arctic soils consist of many trace elements, as well as very large quantities of the carbon, nitrogen, and phosphorous very important to the ecosystem. These elements are essential to processes of mineralization and respiration and nutrient distribution, and because decomposition processes of Arctic tundra soils respond to temperature increase more than other types of region soils, they stand to be very greatly affected by both global warming and other sources of heat input. Increased water flow which can result from melting of permafrost also temporarily increase nutrient distribution and lengthen the growing season for certain plants, particularly *E. vaginatum*, a species of cottongrass sedges. Increased soil flow increases heat flux, which leads to deeper thaw and therefore magnifies the effect.(Chapin 1988)

Concern also arises that the Arctic soils may contribute to greenhouse gas emissions due to this increase in decomposition of organic matter. Most soil organic carbon is found in the active layer of the soil, and it varies in amount depending on such formations as ice wedges, which melt to form polygons with either "high-centers" or "low-centers" that drain in different ways. The proportion of soil organic carbon in the upper permafrost is directly related to the influence of soil moisture on active-layer thickness in that better drained soils have more carbon in the active layer. With global warming and increased heat, the active layer thickness may increase by 20-30%, increasing cryoturbation, thermal erosion, and intensified thaw-lake cycles. Thaw lakes contain peat in frozen subsoil which would also decompose when melted, increasing emissions.

Permafrost

Examining the soil of the 1002 region, one cannot ignore the presence of permafrost, or permanently frozen soil, which underlies 80% of Alaska and remains a central issue in the debate about oil drilling. The surface soils are frozen all but three months of the year, and the permafrost below them penetrate the ground to an average of about 660 m deep.

Permafrost can be either thaw-stable or non thaw-stable, depending on the type and percentage water of the soil it is made of. Permafrost in more fine-grained soils like loess (silty) tend to thaw, sink, and create thermokarsts more often. Permafrost thaws from heat input, such as global warming or human activity, as well as the clearing of vegetation which insulates the ground.

More on permafrost can be found in the Hydrology section

Physical Environment - Soil Microbial Processes

Microbial Processes and Plant Nutrient Availability in Arctic soils

Several characteristics of arctic soils influence microbial activity, nutrient mineralization, and nutrient availability to plants and will certainly figure prominently in changes in these processes in a warmer arctic climate. Arctic soils are generally overlain by a dense mat of organic matter and vegetation, wet for at least part of the year and permanently frozen at some depth. These factors combine to lower summer soil temperatures, impede the progression and decrease the depth of seasonal thawing, and maintain relatively high soil moisture content. Cold, wet soil environments and short summers slow organic matter decomposition and nutrient mineralization and severely restrict nutrient availability to plants.

The accumulation of organic matter in arctic soils is determined largely by the combined effects of temperature and moisture on decomposition and primary production. Because of climatic variation among arctic regions, the amounts of organic matter and nutrients in tundra soils vary across broad geographic scales. Organic matter often accumulates at depth in permanently frozen peats in relatively wet arctic regions such as the coastal plain on northern Alaska.

Organic carbon increases with moisture, from low amounts in well-drained beach-ridge ecosystems with cushion plant-lichen communities. Such an overall pattern of organic carbon increasing with moisture from well- to poorly drained ecosystems also occurs in Alaska's coastal and foothill tundra regions
Well-drained soils are less common in patterned ground regions with little relief, such as the Alaskan coastal plain, where more than 85% of soils are moist to poorly drained. Moist soils with dense organic mats(5-40cm thick), intermediate thaw depths, and divers plant communities dominated by tussock-forming sedges occupy gently sloping land in much of the Low Arctic.

Organic matter and moisture content are important determinants of soil temperature, thaw depth, cation exchange capacity, aeration, redox potential, and other properties affecting biological processes in soils. Decomposition rates and soil moisture balances will likely be affected by the warmer temperatures predicted for the Arctic. The resulting changes in soil organic matter, moisture and microbial processes in ecosystems will alter the amounts, seasonality, and forms of mineral nutrients available to plants. A warmer climate will likely have different overall effects on soil properties and on nutrient cycling in dry, moist, and wet arctic ecosystems.
Source: CHAPIN, F.S., JEFFERIES, R.L., REYNOLDS, J.F., SHAVER, G.R. Arctic Ecosystem in a Changing Climate: An Ecophysiological Perspective, 1991. P. 281-283.

Microbial and soil Processes

Nutrient cycling and fertilization studies in arctic ecosystems show that plant growth is strongly limited by nutrient availability. Primary production is often nitrogen-limited, but phosphorus (especially in organic soils) or nitrogen and phosphorus together can also limit production.

Arctic ecosystems are generally conservative of nutrients accumulating large amounts in soil organic matter pools with very long turnover times. Because of these characteristically slow turnover rates and, in some ecosystems, the gradual burial of organic matter in permafrost, nutrients become available to plants at very low rates. Long turnover time result from slow decomposition, which can become a bottleneck in nutrient cycling rates. Differences among ecosystem types in soil microclimate and decomposition may explain the inverse relationships between soil nutrient stocks and nutrient cycling rates or primary productivity as reported, for example, on Alaska's northern coast. Slow decomposition leads to greater accumulation of organic matter in soil and can lower nutrient mineralization rates, thereby decreasing primary productivity.

Source:
CHAPIN, F.S., JEFFERIES, R.L., REYNOLDS, J.F., SHAVER, G.R. Arctic Ecosystem in a Changing Climate: An Ecophysiological Perspective, 1991.

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Physical Environment - Nutrient Cycles

In order to understand the ANWR ecosystem, it is also necessary to investigate the energy and nutrient cycles. The carbon balance of the ecosystem has been highly influenced by global climate changes and CO2 content changes. The arctic contains 11% of the world's organic matter pool, and within the arctic tundra ecosystems, there are both carbon sinks and carbon sources. Vegetation changes in the Alaskan tussock tundra over the past decade has brought about important feedbacks on the region's biogeochemical cycles, mostly through altered rates of carbon and energy exchange between biosphere and atmosphere. Modeling analysis suggests that the source/sink strength of tundra depends on changes in photosynthesis that result from the partitioning of nitrogen between vegetation and soils, and on changes in soil moisture, which affect soil respiration rates. All of these factors may be affected by machine and human activity in the region and disturbances in the permafrost.

Nutrient cycling and fertilization studies in arctic ecosystems show that plant growth is strongly limited by nutrient availability. Such activity depends highly on decomposition, nitrogen mineralization, phosphorous availability, and controls on carbon and nutrient cycles, which in turn depend on temperature, moisture, decomposability of litter inputs, depth of thaw, etc.

Current Net Ecosystem Carbon Storage and Flux

Carbon pools and rates of carbon accumulation vary, depending on vegetation type and environmental conditions.

More than 90% of the carbon in arctic ecosystems is located in soils, with even higher percentages (98%) in soils of northern peatlands. In upland boreal forest, in contrast, only about 55% of the ecosystem carbon is found in the soil. Not only is the proportion of soil carbon substantial, but so are the absolute amounts. Arctic tundra has 55 Pg (petagrams) of carbon stored as soil organic matter in the A horizon, compared with 87.5 Pg in non-peatland boreal forest and 122 Pg in forest peatlands and Gorham's estimates of 455 Pg C are considerably higher (1991).

Tussock and wet sedge tundra soils account for the bulk of circumpolar tundra carbon stores because they have large amounts of carbon per square meter and cover large areas. Although per unit area carbon storage in polar semi-deserts is only about one-half that in the wet sedge tundra, the greater extent of these semi-deserts results in carbon stores approaching those of wet sedge tundra.

For these large stores of soil organic matter to have accumulated in northern ecosystems, production must have exceeded decomposition at some time in the past. Recent estimates indicate that northern ecosystems still constitute a small net sink for atmospheric carbon; current accumulation rates, however, are difficult to assess (Post, 1990; Gorham, 1991). Because the rates vary with conditions and ecosystem type, soil carbon accumulation is positive in some areas and negative in others. The overall balance is still uncertain (Chapin 1991).

Carbon Balance of Arctic Plants and Ecosystems(and the relation with global warming)

The carbon cycle is strongly correlated with climate in the region, as well as the global climate dynamics. Because of the large amount of carbon present in northern soils and the presumed sensitivity of soil carbon accumulation or loss to climate change, northern ecosystems may be particularly important to global carbon balance in the future. Between 250 and 455 petagrams of carbon are present in the permafrost and seasonally thawed soil layers -- about one-third the total world pool of soil carbon. Warmer soils could deepen the active layer and lead to thermokarst and the eventual loss of permafrost over much of the Arctic and the boreal forest.

These changes could in turn alter arctic hydrology, drying the upper soil layers and increasing decomposition rates. As a result, much of the carbon now stored in the active soil layer and permafrost could be released to the atmosphere, thereby increasing CO2 emissions and exacerbating CO2-induced warming. Alternatively, plant communities and vegetation can be changed because of the increase in atmospheric CO2 and nutrient availability. New communities might be taller and have higher rates of primary productivity than does extant vegetation. The net result could be higher primary productivity, increased carbon storage in plant biomass, and a negative feedback on global atmospheric CO2.

Arctic and boreal forest ecosystems are unique in their potentially positive and negative response to elevated CO2 and associated climate change. The arctic ecosystem is also unique in its capacity for massive continuing, long term carbon accumulation because of its permafrost, and they are also particularly sensitive to global warming. Thus it can be seen that it is important to discuss the major processes and controls on carbon cycling in arctic ecosystems, and the likely effects of elevated atmospheric CO2 and concomitant climate change on carbon storage" (Chapin 1991).

Global warming, vegetation changes, and the nutrient cycles

Under global warming, temperature and precipitation changes in arctic regions are occurring already. In much of Alaska, approximately 1ºC per decade of warming has been observed. Vegetation changes have been recorded in Alaskan tussock tundra over the past decade (Chapin et al. 1995), and these changes are expected to have important feedbacks on the region's biogeochemical cycles through altered rates of C exchange between biosphere and atmosphere, and changes in the region's energy balance.

The arctic tundra ecosystem consists of both C sinks and sources. Detailed modeling analysis of arctic biogeochemistry (McKane et al. 1997) suggest that the source/sink strength of tundra depends on changes in photosynthesis that result from the partitioning of nitrogen (NO) between vegetation and soils, and on changes in soil moisture, which affect soil respiration rates.

From Arctic Ecosystem in a Changing Climate: An Ecophysiological Perspective : "The limitations of photosynthesis by low temperatures and low solar radiation has been clearly demonstrated and simulated for arctic vascular plants(Miller et al. 1976; Limbach et al. 1982; Tenhunen et al. 1994) But, because of the saturating response of photosynthesis to light, day length is an additional important limiting factor to productivity." "While moisture stress has no impact on productivity at some of the mean climate conditions, photosynthesis is vulnerable to changes in soil water potential and hydraulic constraints on water transport." A reduction in soil water potential can cause stomatal closure, to balance transpiration against reduced soil water intake. Lower hydraulic conductance can lead to stomatal closure and reduce gross primary productivity as rates of water supply are constrained by the characteristics of the vascular system. Photosynthesis in arctic ecosystems is linked closely to the hydrological cycle. C loss from ecosystems is also linked to soil moisture (Oechel et al. 1993).

Works cited:

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