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THE ECOLOGICAL IMPACT OF NORTHERN PETROLEUM DEVELOPMENT

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THE ECOLOGICAL IMPACT OF NORTHERN PETROLEUM DEVELOPMENT[1]

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Review articles and conference proceedings on the documented and suspected ecological effects of northern petroleum development have been produced at a rate that seems to have exceeded the rate of discovery of commercial showings of hydrocarbons in the north. These reviews have ranged from photo-essays (Klein 1970) to summaries from petroleum operators on the suspected environmental side-effects of their activities (Rempel 1970) to the annotated bibliography of permafrost, vegetation, wildlife, and landform relationships (Roberts-Pichette 1972) to the Canadian Pipeline Conference over a year ago (Leggett and MacFarlane 1972). In turn, many research papers have been written on various aspects, some of which are referenced here.

Much of the ecological research underway in the Canadian Arctic is sponsored by the petroleum industry (Environment Protection Board, Renewable Resources Consulting Services Ltd., Williams Brothers Canada Ltd.) and the Federal Government (Government of Canada 1972a and 1972b, and the Arctic Land Use Research programme of Department of Indian and Northern Affairs), and part of the research is funded jointly by federal agencies and industry (portions of the ALUR programme and the IBP Devon Island ecosystem study). We are proud in Canada that we are helping to lead the way on jointly funded research by industry and government, for the land owners and resource users have a collective responsibility to society to manage both our renewable and non-renewable resources in a wise manner.

Arctic lands, those treeless areas beyond the climatic limit of forest, have a special interest to this group of petroleum developers, government regulators and biology investigators because we want to utilize these northern resources, but in a manner that will maintain the rights of native northern peoples and the biological health of the land and water in these ecological systems. Our ecological concerns center on two unique aspects of the Arctic: 1) the biological simplicity of the ecosystems in terms of the limited number of species and therefore the greater potential danger in eliminating a key species within the food chain; and, 2) the ever-presence of permafrost and the potential for severe terrain modification should it be ice-rich.

The objective of this paper is to present biological information from land, fresh water, and marine environments on how these systems may react to various perturbations associated with the exploration, development and transportation phases of arctic oil and gas development. This paper will not discuss the ecological effects of northern mining activities. For the petroleum industry most emphasis in this paper will be upon the ecological effects of the development and transportation phases.

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CHARACTERISTICS OF THE LOW AND HIGH ARCTIC

The Arctic, taken as the area beyond the climatic limit of trees, covers about 2.5 million km^2 or 23% of the land surface of Canada. Over this vast area climate, geologic substrates, topography, and biological diversity vary considerably. Much of the mainland tundra is on poorly drained lands of the Canadian Shield, lacking sedimentary basins for oil and gas. To the north, the western islands of the Arctic Archipelago are low rolling lands of Paleozoic to Cenozoic sediments with surface soils that are typically sandy or gravelly, though silty soils and rock strewn (feldmark) areas occur. The eastern islands contain mountain ranges and plateaus of Precambrian granite with younger sediments on the flanks and valleys. Glaciers are common on Baffin, Devon, Axel Heiberg, and Ellesmere Islands while only small glacier remnants occur on Melville Island to the west. The High Arctic lies mostly north of 72°.

Climatically there are considerable differences, ranging from maritime climates along the mainland north coast, southeast to Baffin Island and on the Ungava Peninsula of Quebec to more continental climates in the northern islands and the inland areas of the Districts of Keewatin and Mackenzie (Bird 1967). In the northern islands mean annual temperature averages -16° to -19° C and annual precipitation 6 to 14 cm. The more southern maritime climates have a mean annual temperature of -9° to -11° C and annual precipitation of 15 to 38 cm. In all areas most of the precipitation comes as snow, though summer fog and light drizzle are common. Strong winds, especially in winter, characterize these lands.

Permafrost underlays all of the Canadian Arctic although its thickness varies from 100 to 400 m on the mainland and is generally over 350 m thick in the arctic islands, based upon limited data (Brown, R.J.E. 1970). Permafrost temperatures in the Low Arctic are warmer than in the High Arctic, as are mean annual air temperatures. In the Mackenzie Delta, ground temperatures at 10 to 30 m are -3° to -4° C (Brown, R.J.E. 1970) and in the islands ground temperatures of -11° to -13° C occur at depths of 15 to 30 m (Brown 1972). Although depth of the active layer is related to thawing indices and terrain characteristics, including vegetation, soil texture, and soil water content (Brown 1972), active layer depths do not differ as much from the Low to the High Arctic as one might expect. In many Low Arctic vegetation types, maximum thaw is 30 to 50 cm and the same is true for much of the High Arctic. Coarse textured soils thaw to a depth of 1 to 2 m in the Low Arctic and at least to 1 m in the High Arctic. Massive ice within permafrost is well documented from the Low Arctic (Brown, J. 1970, Mackay 1971, Mackay 1972, and others) but only recently has the extent and potential massiveness of permafrost ice been recognized in the High Arctic (Brown 1972). These include ice masses and wedges, even in gravel deposits.

Kaiser et al. (1972) have divided Canada into grids of 322 km on a side and calculated the number of bird and mammal species in each quadrat. Mainland arctic quadrats northwest of Hudson Bay range from 44 to 74 species. The three arctic quadrats east and west of the Mackenzie Delta contain 59, 64, and 75 species. In sharp contrast, western Victoria and Banks Island have 40, 36, and 35 species while the four quadrats on Ellesmere and Axel Heiberg Islands contain only 22 and 26. The lowest numbers are found in the two quadrats of the western Queen Elizabeth Islands, (Prince Patrick, Borden, Mackenzie King, and Ellef Ringnes), where only 20 and 21 species occur. These islands face the cold permanent arctic ice pack to the west. The best environmental correlations with species diversity were found with mean July temperature and number of daylight hours with bright sun.

On the botanical side there are about 600 species of vascular (flowering) plants in the Low Arctic of the Mackenzie Delta, Yukon and Alaska (Porsild 1951). In the southern High Arctic, Victoria Island has 207 species and Banks Island 169 species (Packer 1969). Further north, Devon, Axel Heiberg, and Melville Islands have 100 to 111 species while Cornwallis, Bathurst, Prince Patrick, and Ellef Ringnes Islands have only 49 to 81 species (Packer 1969). These reductions in numbers of animal and plant species are not just the result of smaller land masses, but result mostly from reduced diversity of land forms (habitats) and an increase in climatic severity. Only a few species can tolerate these extreme conditions. These conditions include very limited availability of nitrogen, cold soils, and soils that typically dry rapidly in summer. Savile (1972) has suggested that for more continental portions of the High Arctic (uplands) water supply seems to be more limiting than nitrogen. In these upland sites in the High Arctic, available water is more limiting than in the Low Arctic but only future research will determine the magnitude of these differences.

Plant cover in the Low Arctic is generally 80 to 100% with most of this contributed by flowering plants. In many areas dwarf heath shrubs (5 to 20 cm tall) or low shrubs of willow and birch (25 to 50 cm tall) are important along with numerous grasses, sedges (25 to 100 cm tall) lichens and mosses. Taller shrubs (1 to 5 m) typically occur along river terraces, steep slopes, and small stream channels. In the Arctic Archipelago small areas of heath shrubs (2 to 10 cm) occur in the warmest habitats, but most grasses and sedges are only 10 to 25 cm tall and most other species are 2 to 10 cm in height. Plant cover of 80 to 100% is limited in the High Arctic to small lowlands dominated by sedges, grasses and mosses. Over vast areas, Polar Deserts have 0 to 5% flowering plant cover with lichens and mosses adding an additional 1 to 20%. The relatively more lush Polar Semi-Deserts, including Polar Steppe, have a 5 to 20% flowering plant cover, while mosses and lichens contribute an additional 20 to 60% in many areas.

Because of the role that peat plays in latent heat transfer, and therefore the rate and magnitude of summer thaw, the last comparisons consider peat thickness. Over much of the tundra and forest-tundra area, peat thickness averages 10 to 30 cm (Wein 1971a) while in wetlands and raised center polygons in the Mackenzie Delta and the arctic coast to Prudhoe Bay, peats may be 1 to 3+ m deep. In the Low Arctic the active layer in tundra and forest-tundra areas is less influenced by the kind of plant community than by soil drainage and water content (Wein 1971a). In the High Arctic peat 10 to 30 cm occurs only in lowland sedge-grass wet meadows, where its role in surface energy budgets is similar to that of surface peats on the mainland. Elsewhere in the islands there is little if any peat accumulation.

INFLUENCES OF CURRENT PRACTICES ON VARIOUS RESOURCES

Land Use and Vegetation Resources

In the exploration phase of oil and gas development, terrain disturbances are associated with: 1) intensive activity at well sites, landing strips and camps; 2) extensive activity along seismic lines; and, 3) miscellaneous overland movement (Barnett and Kuc 1972). With the shift to oil and gas field production, terrain disturbances associated with intensive activity of pipeline construction, haul roads, supply camps, gravel sources, pumping stations and pipeline gathering fields will add new environmental concerns. These terrain disturbances will include changes in hillside and river crossing slope stability, changes in stream drainage and impoundment of water, drainage of wetlands, general surface disturbance potentially resulting in increases in siltation, and increased forest and tundra fires.

While there are documented examples of severe terrain damage from the earlier days of northern petroleum exploration in the Low Arctic (Hok 1969, Klein 1970, Hernandez 1973a), current summer and winter operations have greatly reduced, and in some cases, eliminated biologically significant surface disturbance (Bliss and Wein 1972a, Hernandez 1973a, Kerfoot 1972). Much of the recent damage to terrain and vegetation has resulted from unanticipated needs for moving equipment or supplies over terrain seasonally unsuitable for vehicles. In general this is a minor component at the present time, especially in mainland Canada, and these surfaces are quite rapidly invaded by native species (Hernandez 1973a). Surface disturbance by various types of off-road vehicles has also been documented in the Arctic Islands (French 1971, Kevan 1971, Babb and Bliss 1974) and on the Alaska north slope by Burt (1970).

In discussing the ecological influences of vehicles, it is necessary to distinguish at least three broad categories of use: 1) temporary winter roads constructed from snow or snow and ice; (2) temporary or permanent gravel roads; and, 3) off-road summer or winter travel without road preparation. Road construction is slow and expensive in the Low Arctic and during the exploration phase of development, temporary roads are most desirable. For these reasons and also because of the general shortage of gravel in the Mackenzie Delta, different kinds of road construction have been used, although once the production phase begins, gravel roads will be needed at least in the oil fields.

Where lakes are numerous they have been used for winter travel with road construction limited to the overland portions of the route. In lowland areas where sedges predominate on thick peats, roads of compacted snow are sufficient. While plant tops may be crushed with road construction and use, regrowth each year occurs from the underground stems. In upland areas with soil or cottongrass tussock hummocks, experience shows that roads of snow and ice result in degradation of only the hummock tops. Rapid regrowth takes place from plants remaining in inter-hummock and hummock side microsites (Lambert 1972). When only compacted snow is used the hummocks are generally degraded to base level and the entire surface is churned. This destroys most plant stems and roots, especially the willow, alder, and dwarf birch shrubs that dominate these upland sites (Hernandez 1973a). Although little plant regrowth occurs in summer, these road beds do not lead to erosion or subsidence problems unless the peat base is destroyed and there is massive ice below. Reseeding may be necessary on most of these roads following abandonment, for natural reinvasion is slowed on these peat surfaces that dry in summer. Where hummocks are prominent, resulting in uneven surfaces, gravel has sometimes been added to provide a smoother road bed. If the gravel can be kept to a thickness of 10 to 15 cm, plants will generally grow up through it the following summer. There is no evidence that gravel spread over undisturbed plant surfaces leads to increased thaw depths, and it may lead to reduced thaw. For single moves of well-site equipment and with adequate winter snow cover, experience shows that 170 to 180 loads of 20 to 30 tons each can be moved over soil and sedge hummock terrain with very little surface disturbance. Kerfoot (1972) has recommended that snow packed winter roads should not be used more than two winters and that snow-ice roads should be more widely used, especially where winter snow is scant and where roads will be used several years. While true for some areas, in others the use of the same road for more than two years, provided the peat layer continues to insulate against excessive summer thaw, is less damaging than a series of parallel roads across the terrain. For pipeline construction, thick snow-ice roads may be best.

In summary, research data and observations of numerous winter roads show that different kinds of construction are desirable depending upon the terrain, snow conditions, and anticipated magnitude of road use. Where possible, travel on lakes, rivers and lowland sedge lands is preferable to upland roads (Bliss and Wein 1972a, Hernandez 1973a). Research is underway on the long-term impact of different kinds of off-road vehicles, load weights and number of passes, all in relation to terrain types (Harwood and Yong 1972, Radforth 1972). These surfaces will be checked periodically for plant regrowth and permafrost table level (Radforth 1972).

Much of the concern over seismic lines, winter roads, and old well sites results from their conspicuousness from the air. Although these features occupy less than 2% of the landscape, they are aesthetically displeasing in an otherwise pristine landscape and for this reason have attracted so much attention.

While several roads were initially built by blading the active layer into a strip to serve as a road base, the adjacent canals with a quagmire between soon showed this to be a poor practice (Brooks et al. 1972). Winter construction of permanent roads is feasible, provided adequate tests are made on the ice content of the fill. This is especially important where frozen silts are used. Experinece has shown that permanent roads should be built of gravel by placing the fill directly over the undisturbed tundra vegetation and peat. The typical 1.5 to 2.0 m thick gravel road can be reduced in thickness by placing several centimeters of insulation at the ground surface. However, there is some advantage in allowing the permafrost table to penetrate the road base, for this helps to prevent gravel from lateral movement. Should movement occur over the undisturbed vegetation, the insulative and road bed support properties would be reduced.

One of the major concerns of permanent roads and bermed pipelines is that these structures will effectively block surface drainage of spring melt waters. Unless culverts are placed at frequent intervals and designed to prevent ponding, water will accumulate with the potential of accelerating summer thaw adjacent to the structure, or lead to washouts (Stokes 1971). This was a problem in the 1971-72 winter construction of the Mackenzie Highway south of Inuvik. There was an inadequate placement of culverts on gentle slopes which resulted in numerous washouts of the road following spring melt and water ponding. Problems of slope stability and drainage for a proposed arctic gas pipeline have been presented by Hardy and Morrison (1972).

Few permanent roads have been constructed outside of major settlements in the High Arctic. Most vehicle movement results from winter seismic and oil-rig activity, though some of these operations have occurred in summer. In Polar Deserts where there is little plant cover, off-road vehicle use has resulted in little or no rutting (almost regardless of soil texture), provided the surface soils dried after spring snowmelt (Barnett and Kuc 1972). Rutting occurs in the finer textured soils, especially when they are near saturation in early summer. On some slopes, soil instability results from active layer meltwater concentrated along the permafrost table. This water rises to the surface on the lower slope, keeps the soils moist all summer, and may result in natural slumping where the soils are saturated and there is little plant cover (Beschel 1963, Babb and Bliss 1974). Such sites may offer problems for both summer vehicle use and construction activities.

Silty soils, as on the Sabine Peninsula, Melville Island and on King Christian Island, show considerable rutting with summer movement of supplies. Where track vehicles have moved through lowland grass-sedge-moss marshes in summer, rutting comparable to that on the mainland has occurred. If intensive development takes place in these limited lush areas, much of the essential winter range of muskox may be lost (Bliss and Wein 1972b, Bliss 1974). Key areas of this kind occur on the north coast of Devon Island, the fjords and coastal areas of Axel Heiberg and Ellesmere Islands, much of the southern and southeastern portions of Melville Island, central Bathurst Island, the Mould Bay area of Prince Patrick Island (Bliss 1974), and the northwest coast of Cornwallis Island (Thorsteinsson 1958). These relatively lush high arctic habitats provide much of the meager diversity of animals and plants, yet they occupy less than 2% of these Polar Deserts and Semi-Deserts and they do not appear on maps of critical biological areas that have been prepared for use of oil and gas exploration crews.

Natural mass-wasting in high arctic environments seems quite rapid although snow cover and water equivalent are low and the snow-free season is only 45 to 60 days. The sharp dendritic stream patterns and their abrupt headward erosion, as well as the large delta areas associated with rivers that are small in mid-summer, all attest to this. McCann et al. (1972) report that 90% of annual run-off occurred during spring melt-water flood and that discharge fluctuated diurnally in relation to incoming radiation. Sediment transport along the channel bed and in suspension occurred during flood while dissolved sediment was the primary fraction during most of the flow season. They studied the Mecham River in southern Cornwallis Island and Jason's Creek on southern Devon Island.

The senior author has observed many streams and rivers in the arctic islands that carry a heavy dissolved and suspended sediment load in mid to late summer. Water of this quality supplies most oil company camps in summer.

Scraped runways with small piles of soil at their edge and rutting from the summer use of vehicles may result in increased local snow accumulation followed by accelerated erosion during spring melt. This is very evident on southern Ellef Ringnes and King Christian Island where two years of water erosion and some increase in thaw depth have resulted in gullies 1 to 2 m deep and 2 to 4 m wide. Because of the limited amount of plant cover and the small size of plant roots, soil erosion is not retarded as it is in the Low Arctic or temperate regions. Accelerated sheet and gully erosion may prove to be a major environmental problem in building and maintaining gas pipeline facilities in the Arctic Archipelago.

Fires are a common phenomenon in the boreal forest or forest tundra. Tundra fires have not been so widespread because of discontinuities in plant cover, low combustible biomass and water saturation of peat profiles in many areas (Wein and Bliss 1973a). Though fewer species participated, production in burned cottongrass tussock communities examined at two sites in Alaska and two near Inuvik, N.W.T. approached that of control plots after two years. The active layer was generally 50% greater by autumn. *Eriophorum vaginatum* ssp. *spissum* seedlings were abundant the first year but few survived into the second season. A high nutrient content measured in plants on the burn may be due to increased soil volume available for rooting, nutrients released by the fire, or to increased microbial activity in the warmer soils (Wein and Bliss 1973a).

While the above study indicates that cottongrass communities may recover quite rapidly (7 to 17 years) after fire, the increased thaw depth, potential ice melt, slumpage, and sheet erosion are some of the major environmental concerns. Other concerns center on the loss of winter forage for caribou grazing (Scotter 1964), though research has shown that lichens have a low nutrient content and that other forage plants are substituted by caribou (Kelsall 1968). An important aspect of some of the current vegetation survey research along the proposed pipeline routes is an assessment of fire hazard of the various forest, forest-tundra and tundra plant communities (Wein 1971a).

One of the most extensively and intensively studied aspects of arctic biology in relation to pipelines has been that of revegetation. Studies have been conducted in Alaska by Alyeska Pipeline, Atlantic Richfield Corp., and the University of Alaska Agriculture Research Station, and in Canada by Environment Protection Board, Williams Brothers Canada Ltd., and the University of Alberta Botany Department. The Canadian studies have included over 25 species of grass, legumes, and other forbs, most of them native north of the 60th parallel. Test plots have been established at the gas test loop facilities at Norman Wells (Wein 1971b, Hernandez 1973b), Sans Sault (Williams Brothers Canada Ltd. 1972) and Prudhoe Bay, Alaska (Wein 1971b, Hernandez 1973b) and by the latter researchers and Younkin (1972) near Inuvik and Tuktoyaktuk, N.W.T. The results to date show that the commercial varieties canon Canada bluegrass, nugget Kentucky bluegrass, engmo timothy, meadow foxtail, slender wheatgrass, and arctared creeping red fescue do best in overwintering, dry matter production, and/or ground cover (Bliss and Wein 1972a). To this list are added the native grasses *Arctagrostis latifolia* and *Calamagrostis canadensis* which have a high germination rate, slow initial establishment, but rapid growth with rhizome development the second year (Younkin 1973). These grasses are common along seismic lines and old well sites in the Mackenzie Delta. In contrast, *Eriophorum vaginatum* ssp. *spissum* is important in the native vegetation yet relatively uncommon in disturbed soils. Its rate of seed germination, especially in cold soils is very low (Younkin 1973). Data show that oats and rye provide a quick cover within the northern forest (Norman Wells), but their value as a nurse crop with perennial grasses has not been established. Seed mixes are proving successful in the northern forested areas (Hernandez 1973b), yet the data for the past two years indicate that small rodents and caribou are attracted to these nutrient rich plants and that grazing may become a problem in maintaining a cover. Fertilizer levels (110 to 220 kg/ha) of each element have been investigated along with the general seeding rates (33 to 55 kg/ha). Studies show that nitrogen: phosphorous ratios of 1:1 or 1:2 give good growth when reseeding grasses (Younkin 1972). To maintain maximum growth, refertilizing every 2-3 years may be necessary. These higher fertility levels favor mosses in some moist sites (D. Dabbs, personal communication) which is ideal for reducing soil heat flux. Experimental data for two years indicate that the major agronomic species tested show little ability to become established in the native vegetation (Hernandez 1973b). Preliminary data indicate that in moist sites the establishment of willow-cuttings is very successful (D. Dabbs, personal communication).

Major problems in any reseeding program will be to apply the seed in late fall before the first snows or to seed in spring as snow melt occurs. The dry summer with little rain and any coarse-textured berm materials will be a detriment to plant establishment. Other factors that will limit plant establishment and growth are warm surface soils and high soil water evaporation rates with a buried oil line, or cold surfaces and possibly very shallow active layers with a refrigerated gas line (Bliss and Wein 1972a). Herbivore grazing coupled with moose and caribou trampling will make it difficult to maintain a plant cover. Provided gravel is in adequate supply, a gravel berm without reseeding may prove best, restricting seeding to the adjacent right-of-way, unstable slopes, and abandoned haul roads.

In the High Arctic there is little indication, from the native vegetation or natural and man-induced surface disturbances, that reseeding programs will be successful. Pioneer species are rare, and seed production, seedling establishment and plant growth rates are low (Babb and Bliss 1974, Bliss and Wein 1972a and 1972b).

One of the major environmental concerns in designing northern pipelines, wells, transportation facilities, and camps is the relationship of these activities to ice melt, slumpage, and the development of thermokarst topography. Much of the ecological research now underway centers on the impact of construction practices and operational procedures in relation to high ice-content permafrost. The early blading of seismic lines, the movement of off-road vehicles in late spring or summer, and the burning of forest-tundra or tundra vegetation typically result in a 50 to 100% increase in the active layer (Mackay 1970, Hernandez 1973a, Wein and Bliss 1973a). This is true of sites where the peat has been removed or greatly reduced in thickness. In sites where much of the vegetation has been killed with crude oil, the surface albedo greatly changed and transpiration was reduced to a low level, but no significant increase in the active layer resulted (Wein and Bliss 1973b).

Results from an energy budget study conducted on a winter road within a *Picea mariana* forest at Norman Wells (Haag and Bliss 1974a) and within a low shrub-heath tundra community at Tuktoyaktuk, N.W.T. show that a decrease in albedo resulted in an increase in net radiation over the disturbed surfaces (Haag and Bliss 1974b). Decrease of latent heat losses, coupled with increase in soil heat flux on all disturbed surfaces, showed the importance of a plant cover to the energy budget. The increase was least on the oil spill plot because the standing dead vegetation partially shaded the surface while the film of oil retained a higher water content in the peat for part of the summer. Greater soil heat flux in the burn resulted in the development of a deeper active layer. The plants were burned but the peat only partially so, resulting in a more rapid drying of the peat surface and thus a decreased thermal conductivity. On the winter road where the peat was churned and some mineral soil exposed at the surface, latent heat loss was least, soil heat flux the greatest, and the active layer the deepest. Mineral soil mixed with peat showed a higher thermal conductivity early in the season until the surface layers dried, after which thermal conductivity decreased and ground temperatures in the control plot then showed a more rapid increase (Haag and Bliss 1974a).

Thus, the peat layer has its primary influence in delaying thaw of the mineral soil because of its higher water content and a secondary influence of decreasing thermal conductivity as the peat dries. Any operation such as winter seismic using "mushroom shoes" on the bulldozer blade, snow-ice roads, hauling over deep compacted snow, or summer seismic in upland areas once the surface soils have thawed and dried will result in little damage to the vegetation and surface peat. If, however, the peat surface is churned and mixed with mineral soil, as will happen with much of the pipeline construction and now occurs on some winter roads, soil heat flux, soil temperature, and active layer depth will all increase with the potential for meltout and its associated problems. On the revegetation plots, albedo closely approached that of control plots in three years, yet the active layer showed little decrease in depth (Haag and Bliss 1974a). This indicates that grasses and other species will probably be more important in reducing erosion and stabilizing slopes than they are for re-establishing a shallow thaw layer in the first few years, especially in the Low Arctic.

Although the actual effects of pipeline construction and operation on terrain and vegetation are yet to be documented because major pipelines have not been constructed in the north, results are available from an oil test pipeline at Inuvik (Hall et al. 1972) and from gas test pipelines at Norman Wells (Walker 1972), Sans Sault (Hurd 1972) and Prudhoe Bay (Walker 1972). At Inuvik, oil at 70° C circulated through an insulated pipe (5 cm of insulation on bermed pipe and 10 cm of polyurethane insulation on elevated pipe) indicated that both the berm and pile type of construction remained structurally stable without apparent permafrost degradation. Insulation was removed from a section of the bermed pipe and over a 15-month period permafrost melted to a depth of 3 m below the pipeline and the pipe settled about 1.3 m although there was no evidence of slurrying (Hall et al. 1972). Although only long-term data from sites with different ice contents can provide the answers, these data show less pipe deformation than some people predicted.

In the High Arctic, surface disturbance typically results in only 0 to 15% increase in the depth of active layer, even in sites with 100% cover of mosses and vascular plants (Babb and Bliss 1974). In most of these areas there is relatively little vascular plant cover (often 0 to 15%) and the thin layer of lichens and mosses provides little resistance to heat and water fluxes. Thus, in general, the removal of vegetation in the High Arctic is less critical to terrain stability than in the Low Arctic. On simulated bladed plots where the sedges and top 2 to 3 cm of peat were removed, Babb and Bliss (1974) found that albedo decreased about 50%, latent heat and sensible heat losses increased, but soil heat flux increased only slightly, the latter resulting in only a 15% increase in active layer depth. Because plant resistance to water loss is low, much of the High Arctic dries rapidly after snow melt. With drying, thermal conductivity of the surface soil is reduced. The cold soils below act as a site of condensation and moisture accumulation. The resulting steep moisture gradient and the development of saturated soil at the permafrost table may act as a lubricant and lead to massive slides on slopes (Babb and Bliss 1974). In Polar Semi-Deserts where vascular plants, lichens and mosses account for a 20 to over 50% plant cover, surface soils remain moist, largely the result of crustose lichens increasing the resistance to latent heat of evaporation in comparison with fruticose and foliose lichens which act as a wick (Addison 1972). Adjacent areas without these lichens and vascular plants, sites that range from sands to silts and clays, frequently have very dry surface soils by mid-July.

Wildlife Resources

The useable wildlife species of the north include caribou, muskoxen, moose, Dall sheep and a variety of fur-bearing mammals, all available on a year-round basis (Canadian Wildlife Service 1972). In addition, a wide variety of birds are present during the summer (Barry and Spencer 1972). Much of the work to date has placed a high priority on the identification and inventory of critical areas such as caribou calving grounds, migration routes, nesting and staging areas for geese, denning sites for bears, and locations of seabird colonies (Canadian Wildlife Service 1972, Government of Canada 1973).

There are four generally recognized categories of potentially deleterious effects on the wildlife resource. These are: 1) alteration of habitat, lowering its ability to support particular species of wildlife; 2) activity or terrain disturbance deflecting wildlife from important, traditional migration paths; 3) improved access to certain wildlife populations facilitating unprecedented harvest rates; and, 4) activities of man which attract certain species of wildlife or which result in a conflict between man and animals (Macpherson et al. 1972). In a summary of impacts on wildlife as a result of a project such as northern road construction, the following priority subjects were identified on a species basis: for moose, disturbance in the period December to April and destruction of winter habitat through logging, or sand and gravel removal; for grizzlies, removal of sand and gravel from slopes that serve as denning sites; for Dall sheep, harassment by low flying aircraft; for muskrat and beaver, heavy sediment load in runoff due to erosion and change of stream channels; for waterfowl heavy sediment load in the runoff due to erosion, change of stream channels due to road crossings, harassment by man or low flying aircraft, and sand and gravel removal from river islands. While these analyses were done by the Canadian Wildlife Service for the purpose of predicting impact of a northern highway, any gas or oil exploration activities that involve the same kinds of construction activities would be expected to have comparable influences on the wildlife resource. Many of the current studies point to the critical importance of winter habitat of wildlife species (Special Habitat Evaluation Group 1972, Government of Canada 1973).

Weeden and Klein (1971), in a summary of critical wildlife issues, have pointed out that the one major uncertainty is the question of the behavioural reactions of wild animals to oil field activity. These uncertainties include questions such as whether ungulates that are attracted to salt licks that are formed by sodium chloride used in drilling will ingest any toxic materials at these sites, or whether dispersal of muskox herds by helicopter might be exposing them to increased predation.

The limited amount of experimental work that has been carried out on the behavioural responses of wildlife to petroleum development activities has dealt mainly with barren-ground caribou and to a lesser extent with birds. Based on two pipeline simulations at Prudhoe Bay, Alaska, observations on 1,707 encounters suggest that responses of caribou to man-made obstructions differ among groups and individuals according to sex, age class, size and composition of the groups. In most cases, caribou paralleled the man-made barriers for varying distances before returning to their points of origin or seeking access to the other side around the terminals (Child 1972). These studies were concerned with behavioural responses of caribou during only the post-calving period and knowledge is lacking on the seasonal response differences of this species to simulated pipelines. Another area that is poorly documented is the response of caribou to snow cover phenomena adjacent to obstructions that cause snow accumulation. It has been observed during the winter of 1970-71 that caribou in the Yukon were deflected 16 to 24 km in their movements by seismic trails (United States Department of the Interior 1972). One recent survey in the northern Yukon revealed that 36 of 52 seismic lines, trails, roads and airstrips have been used by caribou, presumably because they are reluctant to leave roads or trails when there is deep snow (Renewable Resources Consulting Services Limited 1971a). Another influence of exploration activities upon caribou movements, and not necessarily a detrimental one, is that caribou are known to follow vehicle tracks over tundra in summer (Renewable Resources Consulting Services Limited 1971a). There is a documented example from the northern Yukon where an all-terrain vehicle moved through an area twice in 1958 during the winter. This minor disturbance was sufficient to change the vegetation pattern on the road, with cottongrass now making up approximately 98% of the cover, while adjacent to the road there is a hummocky terrain of willows, birch, sedges and cottongrass. There are no hummocks on the road. This road was used in mid-July of 1971 by thousands of caribou in preference to adjacent hummocky terrain (Renewable Resources

Consulting Services Limited 1971a). There is little documentation to date on whether these deflections of caribou movements are in any way detrimental. For the wooded areas of the north, the actual influence of seismic line deflection of caribou is not known but it is believed that caribou follow learned migratory routes to appropriate seasonal habitats and that deflections by disturbance or altered landscape might produce long-lasting effects (Macpherson et al. 1972).

Turning specifically to seismic exploration activities north of the tree line, from existing information little can be said with assurance on the general influence of tundra seismic lines on caribou and the arctic fox populations, in areas such as Banks Island (Usher 1971). Both of these species appear to be wide-ranging on the island, but there remain questions of whether stress from noise, fumes or higher levels of human activity are in fact stressful to foxes in various seasons or in various stages of their life cycle. Unlike mammals of the mountains and taiga, the caribou on the tundra have no escape habitat and depend on vast open spaces for security. Therefore, heavy use of tundra areas by a variety of vehicles could have detrimental influences on caribou, but considering the enormous area available to caribou and their ability to adjust to even fairly conspicuous habitat changes, such as those created by roads or buildings, it seems unlikely that their welfare will be threatened by development now planned (Brooks et al. 1971). It is known that caribou have an aversion to objects on the skyline and this fact has been used in hunting and deflecting them. Thus, where possible, construction practices should avoid prominent objects on ridgetops utilized by caribou (Calef and Lortie 1971). Calef and Lortie (1971) summarized the literature and their observations by concluding that bermed or buried pipelines would likely be crossed by caribou during normal migration. Construction activities might have to stop during migration should the animals become disturbed.

The Porcupine Herd of the Yukon Territory and Alaska is estimated to number 140,000 animals and, as with other Alaskan herds, it may have increased significantly in the past 20 to 40 years (Hemming 1971). Calef and Lortie (1971) estimated that calves accounted for about 16% of the total herd, about the same as for other Canadian herds, but less than the Nelchina Herd in Alaska (20%). In the High Arctic, where Peary's caribou and muskox populations are small in relation to land areas, increased hunting pressure either by Inuit or by people from southern Canada can be very detrimental. This is well illustrated by the Grise Fiord village, which since 1956 has averaged 25 caribou per winter, with caribou becoming uncommon on southern Ellesmere Island (Riewe 1972). With the change to skidoos and the greater potential hunting area, the yearly kill rose to 75, 46 and 60 the winters of 1968-69, 1969-70, 1970-71. With this level of hunter mobility, the caribou are in danger of being eliminated within the range of hunting on Ellesmere Island (Riewe 1972). This same situation can easily be repeated in the Mackenzie Delta in terms of barren-ground caribou and moose with the combined efficiency of airplane spotters and hunters on skidoos.

Eskers are one particular landform that should be singled out because they possess characteristics that make them attractive to both man and some wildlife species. Eskers usually contain a range of parent material textures, including valuable supplies of gravel. At the same time eskers serve for caribou migration routes, particularly in the eastern arctic mainland, and also as nesting sites for a number of bird species and denning sites for foxes and wolf (Pruitt 1970). If there is massive mining of aggregate materials from eskers and esker complexes it would obviously have some influence on reproductive or migratory habits of these animal species.

Aerial harassment to wildlife results in unnecessary and costly expenditure of energy by animals that are forced to run in a cold environment where food supply is limited. Geist has estimated that a caribou weighing 90 kg which is chased for 10 minutes, then walks for an hour and is excited for another hour, would require 665 kilocalories above the normal 3200 kilocalories needed for daily survival. This equates to 0.90 kg of extra forage per animal per day, and in a large herd could place significant extra demands on forage areas. Harassment is most detrimental at three critical times for caribou: during the fly season, during very cold weather in late winter, and during calving or late pregnancy. Harassment of females both before and after birth of young prejudices the life of both. It is now known that if a female in early gestation loses more than 17% of her body weight, the unborn young is resorbed by the mother (Geist 1971).

One of the localized influences of northern petroleum exploration, documented from the North Slope of Alaska, is associated with the abandonment of hundreds of km of used wire by geophysical companies on the tundra. This wire is a genuine hazard to antlered animals and several instances of caribou becoming fatally entangled in this wire have been observed (Brooks et al. 1971).

Carnivores need to be considered in a class by themselves in arctic areas because, for this group of animals, protection of "range" as such is no guarantee of species survival. For example, species such as barren-ground grizzly or the wolverine are extremely susceptible to over-utilization. Being top carnivores in the food web they exist in small numbers with individuals widely spaced and with relatively weak reproductive potential. Thus the loss of only a few individuals could have a significant effect on species survival. Pruitt (1970) has pointed out that for most human visitors to the tundra a grizzly is automatically a menace to human life, especially if it is sighted from a camp. For grizzly bears, the absence of escape habitat over most of the north makes these animals very vulnerable to hunting. This means that it is well within the limits of possibility for the barren-ground grizzly to become extinct if one imagined a series of exploration camps established at regular intervals throughout the area of the species distribution (Pruitt 1970). Fortunately, the distribution of sedimentary basins will likely preclude such regular establishment of exploration camps throughout the range of barren-ground grizzly. In the case of polar bears, the potential for conflict between bears and man is increasing, especially where people unfamiliar with polar bears are involved as at northern oil drilling camps (Jonkel 1969). The problems of bears lured by garbage have been discussed by Jonkel but he stressed the need for further research in this field.

A 1971 study involving the capture of 150 mammals of several different species on a seismic line area and on a nearby undisturbed control area was unable to demonstrate any significant effect of seismic lines on species composition or density of small mammal populations (Renewable Resources Consulting Services Limited 1971b). It is reported that the open area of seismic lines is frequently a favoured habitat for ptarmigan, especially where recent willow growth is present, and there is also a long list of species of animals and birds that use or cross seismic lines without hesitation.

In preliminary study of wildlife responses to a drilling rig in the Mackenzie Delta, it was found that 43% of the bird species were noticeably less numerous within 2.4 km of the rig during summer drilling operations, 52% were not affected and 5% (2 species) occurred more abundantly near the drilling rig (Barry and Spencer 1972). In particular, geese and swans, when molting or when in family-group flocks with downy young, stayed more than 2.4 km from the drill rig. Helicopters operating at low levels were the most disturbing, directly affecting waterfowl in a circle of at least 2.4 km in diameter and indirectly influencing them by allowing increased predation (by gulls and jaegers) of nests from which waterfowl were disturbed.

Freshwater Resources

The major dangers to aquatic ecosystems in the Arctic are thought to be: 1) land disturbance through excessive use of heavy equipment and construction of ice bridges resulting in increased erosion and siltation; 2) oil seepage and release of other toxic materials; 3) enrichment from discharge of sewage; and 4) man's over-expectation of the Arctic to produce fish, mammals and birds with resulting over-exploitation. There is also an apparent over-expectation of the Arctic to recover after damage or to recycle nutrients in systems that have a low rate of energy flow (Working Group on Water Quality Criteria 1972).

The suspected impact of petroleum related projects, such as pipelines, focus on two broad questions in relation to fish; the physical damage to spawning areas and fish as a result of increased erosion and siltation; and, the inadvertent formation of barriers to fish movement and entrapment of fish (United States Department of the Interior 1970 and 1972, Government of Canada 1972a and 1972b). The following specific hazards to fish are perceived: 1) gravel required for construction, if taken at liberty from stream banks and stream beds, could damage fish spawning and nursery areas and interrupt the production of benthic food organisms; 2) disturbance of the vegetation cover with subsequent silting would be a hazard to fish and benthic invertebrates; 3) wastes associated with construction, maintenance or operation of pipelines could be a hazard to fish particularly if the wastes accumulate during the winter months and concentrate their effects during the short summer; 4) the greatest threat posed by a pipeline is the possibility of an accidental oil spill (Macpherson et al. 1972).

In general terms, clear-running streams are more sensitive to environmental disruption than are turbid streams, and clear streams generally contain more resident fish. In 1971, Shotton sampled 25 rivers and creeks for species of fish and various physical parameters to determine faunistic diversity and to obtain background information on natural siltation. Twenty species were identified, yet only grayling, *Thymallus arcticus*, was a constantly sampled species. Turbid streams with their already high rate of silt load and history of extreme natural events seem less likely to be affected by man-caused physical disruptions. However, chemical contamination would be a danger to both stream types (Hatfield et al. 1972). Migration and spawning of most species take place primarily in spring and fall. One important exception is in arctic char streams which are sensitive to disruption in any season since eggs, fry, juvenile fish or adults would be in the stream at all times of the year (Hatfield et al. 1972).

Charges detonated during geophysical operations in relatively shallow water are directly harmful to fry, juvenile fish and adults. Similarly, ice bridges that are built to transport geophysical equipment pose some problems to fish resources if detritus left by the ice bridge does not allow the unhindered passage of fish. One of the other disturbances experienced by lakes is the frequent practice of using frozen lakes in winter as airstrips. This practice invites the localized concentration of various pollutants on or adjacent to lakes (Bryan et al. 1973).

The northern phenomenon of "icings", where they are man-made, can have an influence on winter survival of aquatic organisms because icings frequently result from the localized freezing of streams to the bottom. There are many examples of icings from natural causes, but man-made causes of icings are equally important. To indicate how easy it is to trigger such disruptions, there are known examples of careless and unknowing compaction of the insulating cover of snow on the ice surface of a stream causing that stream to freeze to the bottom and forcing water to the surface (Thomson 1963). One instance of this is recorded by Thomson at a site about 65 m upstream from a road after someone snowshoed across a small stream. This was enough of a disturbance to the insulating snow cover to cause the stream to freeze to the bottom and to create an icing that eventually encroached upon the road. This example demonstrates how easily winter exploration activities can trigger icings that would disrupt winter life-cycle requirements of aquatic organisms that depend upon continued winter flow of stream water.

Because surface water is very limited after snowmelt in most of the arctic islands, small earthen dams are built for camp and well rig needs. While most of these dams block only small intermittent streams, they may on occasion be built on larger streams that flow from lakes with arctic char populations. The temporary dams should be broken to ensure arctic char migration as well as to restore normal drainage patterns.

Turning to the biological features of freshwater resources in the north, it is noteworthy that unlike most arctic birds and many small mammals that have unstable populations, freshwater populations are very stable. Most fish take longer than their southern counterparts to reach maturity and their populations are composed mainly of individuals of large size and great age (Hunter 1970). Populations of freshwater invertebrates (many requiring more than one year to complete the life cycle) also have longer life spans than southern counterparts. Studies of freshwater populations and nutrient controls of these populations have indicated that nutrition rather than temperature is the important limiting factor for production in arctic freshwater ecosystems. For example, at Meretta Lake, Cornwallis Island, which receives a considerable quantity of sewage effluent after primary treatment, primary productivity was 18 to 40 times greater than in neighbouring Char Lake (Working Group on Water Quality Criteria 1972). This sewage enrichment has changed the lake from one in which benthic production predominates to one in which planktonic production predominates. For two years no young char have been found in this lake, indicating that eutrophication from added sewage may make the lake intolerable to arctic char (Rigler 1972). It is important to note the rapidity with which these major biological changes occurred. The limits of change which may be tolerated without long-lasting degradation of such arctic freshwater areas are not known, but it is known that many arctic birds are dependent on the freshwater invertebrates which emerge in large numbers in the short summer and any change in this pattern could disrupt bird populations.

The freshwaters of northern Canada are believed to have a potential yield of several million kg of fish per year, involving only about 10 species of fish. It is known that the recovery rate of the Arctic's long-lived fish is slow (Hunter 1970) and because of this slow recovery rate arctic fish are more susceptible to the effects of heavy metal pollution than are fish in temperate water bodies.

The well publicized simplicity of northern ecosystems is perhaps best shown in the arctic lakes. Many arctic lakes harbour only one species of primary herbivore and one species of primary carnivore. In these extreme cases of ecosystem simplicity, the removal of just one species means the removal of one whole link in the food chain and therefore ecological disaster for that aquatic ecosystem. This means that the herbivore of some small lakes is far more vulnerable to pollution of all sorts than are the lemmings of the northern tundra (Arctic Institute of North America 1972).

Marine Resources

The waters of the Canadian Arctic Archipelago constitute a network of shallow channels containing 16 major passages. Circulation is weak with dominant movement easterly through the Barrow Strait - Lancaster Sound Passage (Collin 1963). This continuity of surface waters of the Arctic Ocean and Archipelago channels is shown through species composition of zooplankton which displays a remarkable homogeneity within the 100 to 300 m depth range through the Beaufort Sea, western Canadian Arctic and eastern Arctic (Grainger 1965). Added to the relatively limited movements of waters through the passages of the Archipelago is the fact that the total arctic island coastline is estimated to be 43,000 km, approximately 2,200 km greater in length than the circumference of the earth (Government of Canada 1971). This means that any major accumulation of pollutants in the Arctic Ocean, with a limited opportunity for movement out of the area by oceanic currents, has the potential of influencing a very great length of coastline.

In contrast to the Antarctic, in which the region of upwelling is generally considered to be one of the most productive marine areas in the world, the arctic seas are unproductive. Arctic marine areas also show a decrease in species diversity of marine algae as one progresses towards the northwest portions of the Canadian Arctic Archipelago. For example, Lee (1966) found that there were only 31 species of marine algae at Mould Bay, Prince Patrick Island, in contrast to 100 species from study sites in East Greenland. In portions of the arctic regions affected by coastal drainage, the rivers tend to be low in nutrients and are more likely to dilute the nutrient supply than to add to it (Allen 1971). Despite this generally low productivity of arctic seas, there are some specific circumstances in which concentrated chlorophyll does occur. For example, Meguro et al. (1967), working near Barrow, Alaska, found that the chlorophyll content at the bottom side of sea ice was about 100 times greater than that of the sea water under sea ice, leading to the hypothesis that the most important production of the arctic sea is in the ice itself, especially in the spring and early summer. Apollonio (1965) has also studied the standing crop of algae and has found it most abundant on the underside of one-year-old ice. Although utilization of this crop is undetermined, it is assumed to be an important concentrated source of food for marine browsers.

Ringed seals are the commonest and most widely distributed species of seal in the Arctic. They exhibit none of the migratory habits of the harp seal and remain seasonally constant wherever fast ice occurs (Mansfield 1970). The population of ringed seals is not limited by food but by the amount of fast ice suitable for the construction of birth lairs, so any development activities that might be concentrated at the margins of land-fast ice would have a bearing on the welfare of ringed seals.

White whales have a winter range concentrated close to the border of pack ice. These whales grow best at the southern extremity of their range and their typical habitat is estuarine. This is explained by the high productivity of the estuaries compared to the low productivity of northern seas, the ability of white whales to calve in cool and shallow estuarine waters, and to escape competitive predation by having a winter range close to the border of pack ice (Sergeant and Brodie 1969). The bowhead whale also frequents the waters of the Canadian Arctic (Mansfield 1971). Under protection from commercial exploitation, this species of whale is now recovering well after intensive harvest in the last century. The impact of widespread off-shore petroleum development on this species of whale has not been documented.

With care, it should be possible to minimize disturbance to walrus in the arctic because certain hauling-out sites are used habitually and these are usually promentories that have quick access to deep water (Mansfield 1963) and which are sufficiently conspicuous to be identifiable and avoidable by petroleum development activities.

Murres are the most important and abundant sea bird in the northern hemisphere. They play a distinctive role in the ecology of the northern seas because their colonies serve, through the fertilizing effects of potash-rich excrement, to stimulate the growth of small marine organisms (Tuck 1970). Oil pollution poses perhaps the greatest threat to murres, and many incidents are documented from oil spills in Newfoundland waters, particularly in winter when eider ducks and murres concentrate in certain areas.

OIL SPILLS IN THE NORTH

The first oil spill in Canadian arctic waters has come and gone without detailed documentation and without publicity (Arctic Circular 1969). Damage of two barges by ice in Viscount Melville Sound about 190 km west of Resolute Bay on 21 August 1969 resulted in 10,500 barrels of bulk oil sinking, with an unknown quantity of arctic diesel oil escaping into the sea. The actual biological effects of such events remain poorly documented in the literature of arctic waters. Some other northern areas have a longer experience with oil spills. For example, in the Cook Inlet area of Alaska, the production phase has resulted in numerous significant spills of crude oil into Cook Inlet, with 26 spills being recorded in 1968 alone. Transportation of oil has caused most of the serious spills in the Cook Inlet area. From 1966 through May 1968, 12 pipeline breaks occurred in the Inlet itself (Evans 1970).

For an example on land, we may look at the Haines-Fairbanks military pipeline. Since the beginning of operation of this pipeline in 1956 there have been 43 reported ruptures of the 20 cm diameter pipe that traverses 1000 km. In the spring of 1956 it was necessary to remove ice from the pipe at 26 locations. The ice resulted from water that was left in the line during hydrostatic testing. Portions of the line had JP-4 jet fuel in it at the time, and when the line was cut this fuel flowed over the soil surface. Little new vegetation has grown on these areas, except in certain drainage areas where sufficient leaching of the fuel has occurred (Rickard and Deneke 1972).

There is accumulating evidence that oil is more persistent in the environment than was earlier anticipated and that it is taken up readily by aquatic animals (Zitko and Carson 1970, Zitko 1970). However, very little is known about the fate of the oil in the animals and in their food chains. In particular, there is little literature concerning hydrocarbon decomposers in cold regions. It is possible, because of the long generation times of microbes in cold environments, that oil spills in cold terrestrial areas may be one of the few places where microbial inoculation may be beneficial (Hunt 1972). The relatively low nutritional status of many northern sites may add to the problem of microbial breakdown of carbon sources. For microbial populations to expand rapidly they must be able to produce sufficient protein. When a source of oxidizable carbon is almost unlimited, as in an oil spill area, the limiting factor in protein production is often the availability of sufficient nutrients, especially nitrogen and phosphorous. Therefore, one of the obvious ways of increasing the rate of crude oil decomposition is to optimize the concentration of these nutrients (Hunt 1972). Hunt (1972) has estimated that in a cold environment the natural recovery of an oil spill by microbiological mechanisms may take as long as 20 years. There is a relative abundance of aerobic thermophilic bacteria in the arctic regions, in contrast to their relative scarcity in antarctic regions (McBee 1963). It is known that thermophilic bacteria will grow at reduced soil temperatures, but it is not known whether they can actually multiply below the freezing point as do mesophilic bacteria. Knowledge of this kind is necessary if there is to be development of assisted microbiological techniques for oil spill clean-up.

As recently as 1970, McTaggart-Cowan listed 23 areas of work that required an urgent concerted attack by the scientific community on the general subject of petroleum products in a cold environment. Included in the list of recommendations was the suggested need for studies on the long-term effects of petroleum products and dispersants on marine fauna and flora, and also studies on the overall ecological consequences of oil spills in water (McTaggart-Cowan 1970).

Low temperatures which retard evaporation and slow down biological processes, the absence of wave action in areas largely ice-covered, and the confining effects of the ice itself in most arctic waters all tend to inhibit the dispersal of oil spills. It is conceivable that some oil fractions and oil residues would remain relatively unchanged for several years in the Arctic. These circumstances, however, point to one possible advantage for cleanup of oil spills in ice-covered areas because, as Barber (1970, 1971a and 1971b) and Vance (1971) have documented, ice cover can sometimes provide control of spilled oil under arctic conditions.

Brooks and coworkers (1971) have summarized the likely effects of an oil spill on the north coast of Alaska. In their opinion, a large oil spill could conceivably kill most birds frequenting the north coast. Even small quantities of oil on the plummage of nesting birds could cover the eggs with a film that would cause the death of embryos. Polar bears are thought to be vulnerable to exposure to oil which would mat their fur and reduce its heat conserving qualities. Arctic foxes are not apt to encounter oil because they normally do not swim while living on the ice pack. There is some evidence that seals can be harmed by exposure to oil but how oil might effect whales or fish is unknown (Brooks et al. 1971). Tuck (1960) suggested that murres are attracted to soil slicks, mistaking them for schools of fish. Oil smeared on wings reduces flying and diving ability of these birds and also reduces insulation against cold arctic waters. If oil contamination is slight, there is still a chance for oil to be ingested when the birds clean their plummage and small amounts of ingested oil are sufficient to kill murres.

Most of the studies to date that have examined impact on northern freshwater ecosystems have focussed on oil spill questions. In a study to determine the influence of crude oil on plankton primary production in marshwater from near Inuvik, NWT, Dickman (1971) found that primary productivity was 10 times lower in oil-treated samples after a four-hour incubation period than it was in control samples. In this case, the consequences of the drop in productivity are difficult to predict without exact knowledge of the role of algal productivity in the total freshwater energy system.

Other effects of oil on aquatic ecosystems are known from some of the larger animals and waterfowl species. For example, water birds, muskrats, otters and many other widlife species require water that is free from surface oil. Egg-laying by mallards is inhibited when even a small quantity of oil is ingested and oil from plummage coated on eggs has reduced hatching from 21 to 80% (Working Group on Water Quality Criteria 1972). Although some biologists have expressed the opinion that oil spills might have minimum effects on marine mammals, at least one biologist (Pruitt 1970) suspects that a slightly oiled polar bear would survive in a polar sea not much longer than a slightly oiled murre.

Oil appears capable of being absorbed on sea ice where it remains blocked until the ice melts or else is transported. Although commercial fish stocks are few in the arctic seas, one valuable resource is the anadromous arctic char which could be very vulnerable to oil pollution in the estuarine conditions in which it does its principal feeding. This feeding occurs mainly from mid-July to late August, at a time when oil would arrive either down-river or would be deposited from ice stranded in estuaries. In contrast to this potential effect on arctic char, marine mammals are thought to be relatively tolerant to surface oils (Working Group on Water Quality Criteria 1972).

The identification of the underside of arctic sea ice as a focus of primary production is important because it has also been determined by Vance (1971) from oil spill tests on the polar ice floe near Barrow, Alaska, that oil released under ice seeks the highest level and therefore occurs in holes or dislocations of the ice under-surface. In these particular tests there was little water current close to the ice undersurface so that oil attracted to the pockets on the underside of the ice had little tendency to flow away. Although we are not aware of any experimentation on the effects of oil on the diatoms that are concentrated on the underside of ice, it is reasonable to assume from other aquatic studies that primary production would be reduced from any such contact with oil. In relation to marine production as a whole, these findings suggest that in spite of the relatively low rate of primary production throughout the year, the blooming of phytoplankton might subsequently induce local blooming of zooplankton around summer pack ice, which in turn might attract larger sea animals. Therefore, if oil collected on the underside of sea ice does have a detrimental influence on the primary production base, it will also have a potential influence on a number of larger animals.

One can speculate that the greatest impact from oil spills in arctic waters would be at the time of greatest annual biological activity. Apollonio (1971) has indicated that the greatest annual biological activity, considering both marine phytoplankton and algae attached to the bottom side of sea ice, takes place before ice breakup and before summer cloud cover (associated with open water) occurs. The time of this most critical period will vary in different parts of the northern seas but algal blooms are known to begin in mid-April and to peak in mid-June. The phytoplankton bloom is slightly later than the algal bloom and does not last as long. Therefore, if oil were brought into contact with the underside of ice between mid-April and July its effects would likely be biologically greater than if it happened in other months of the year. In a preliminary documentation of an oil spill at Deception Bay, Hudson Strait, Ramseier (1970) indicated that from a spill of 8,200 barrels of arctic diesel oil and 1,300 barrels of gasoline from a coastal tank farm some of the spilled materials did in fact accumulate under the shore-fast ice which constantly moved with the tide in June 1970. A similar fate could be predicted for crude oil because it has a density between that of sea water and that of ice, which would encourage it to accumulate and spread just under the ice. This accumulation, in turn, would also lessen or prevent the volatilization of the lighter parts of crude oil (Dunbar 1971).

For evaluating the impact of oil spills on land it is noteworthy that in tests at the Barrow, Alaska, IBP study area oil sometimes penetrated to the permafrost on the drier soils but did not penetrate much below the organic layer on the wetter sites even when there was heavy application of oil. The failure to detect downward movement of the oil in a wet site after the standing water had drained indicates that most of the volatile fraction of the oil had evaporated before recession of the water, thus increasing the viscosity of the oil and making it relatively immobile in the surface organic matter at the prevailing temperatures (Brown and West 1970). This behaviour seems to provide some restrictions to the zone of influence of an oil spill under northern conditions. However, this reduced mobility of spilled materials also results in prolongation of the side-effects on organisms.

Studies conducted in temperate regions have shown that not all crude oils or their specific components are equally phytotoxic. The same is true for the Arctic where preliminary results indicate that Prudhoe Bay crude is more toxic than the light gravity crude from Norman Wells; the Mackenzie Delta crudes may be somewhat intermediate. Studies initiated in 1970 at Barrow, Alaska (McCowen et al. 1971), Mackenzie Delta (Wein and Bliss 1973b) and Devon Island (Babb and Bliss 1974) all show that crude oil and arctic diesel fuel are lethal to plant parts upon contact. Regrowth from latent buds of *Betula* and *Salix* in upland sites was faster than from new shoots of *Carex* species in wet soils. The latter showed more rapid recovery than dwarf heath shurbs and *Eriophorum vaginatum* ssp. *spissum* in upland better drained sites. *Picea mariana* trees with only a few branches treated with oil began to die in 1972, showing a strong lag effect (Wein and Bliss 1973b). All lichen species were killed by the crude oil as were all mosses other than *Polytrichum juniperinum*. Babb and Bliss (1974) found that lichens were more resistant to diesel toxicity than were vascular plants.

Plant community recovery, measured as percent cover, ranged from 20% in black spruce-alder-heath and medium shrub-alder-heath communities to 33% in a willow-birch-heath community and 55% in a wetland sedge community by August 1971 (Wein and Bliss 1973b). There appeared to be little further recovery in 1972. These data and those of McCowen et al. (1971) show that plant recovery is much faster in wetland than in upland sites. Wein and Bliss (1973b) also found that hot crude oil (90° C) spilled in October penetrated the snow only 5 to 10 cm and that the following spring most plant shoots were dead. Thus winter spilled crude is as detrimental to plants as oil spilled in summer.

Preliminary studies show that there are numerous native microorganisms that use these crudes as an energy source and that microbial utilization occurs relatively rapidly in summer (McCowen et al. 1971, Gossen and Parkinson 1972). The addition of nitrogen and phosphorous can stimulate microbial activity and hasten breakdown of these crudes, for nitrogen becomes limiting with accelerated growth of bacteria and fungi.

Should oil spills occur over land, the immediate removal of oil pools and the diversion of oil to small impoundments that do not drain into larger lakes is encouraged. Unless diking materials are stored at critical locations, winter diking will be difficult and summer diking by stripping the surface vegetation is inappropriate because of the thermal effects of the permafrost. In winter the immediate blading of oil-saturated snow into piles followed by burning may be the least detrimental, though in summer, burning would again lead to accelerated thaw and the loss of the insulative peat layer. Under summer and early fall conditions, the least damaging environmental procedure may be to leave the crude to decompose *in situ* (Bliss and Wein 1972b) once surface oil pools have been recovered.

Although plant regrowth has been quite rapid in these arctic studies, Rickard and Deneke (1972) have shown that 15 years after spills on the Haines-Fairbanks, Alaska, pipeline there is still little plant growth. They attribute this to the non-solubility of petroleum and to very slow leaching of oil components in a region of low precipitation and temperature.

There is no documented information for northern areas on the effects of soil saturation with natural gas. From studies of gas contaminated soils in Kansas, it has been shown that there are substantial increases in total carbon, exchangeable manganese and ferric iron, in gas-saturated soils. A disturbed Fe-Mn relationship is thought to be one of the major factors accounting for the frequently reduced vegetative growth on gas-saturated soils (Adams and Ellis 1960).

In summary, there seems to be a consensus amongst biologists that oil spills are the greatest potential threat to wildlife and fisheries of all the direct effects of oil exploration and development (Weeden and Klein 1971). However, at a recent Arctic Ocean conference in Ditchley, England, there were divergent views about the likely effects of oceanic oil spills upon living resources of the Arctic. Many participants at that conference doubted that such events in the Arctic would be more serious than in warmer and more populated regions. That conference, however, did recognize that the evaporation of toxic volatile fractions is slower and that biological degradation is slower in the north than it is in temperate regions (Roberts 1971).

WASTE DISPOSAL IN THE NORTH

Although traffic damage to northern terrain seems to be of prime concern at present, many experienced northern workers have suggested that a larger concern should be that of solid waste disposal, including the side-effects of incineration as a waste disposal procedure. One of the most important points on the question of waste disposal in the Arctic is the fact that the time frame for breakdown of waste materials is so incongruent with the time frame for man's activities. Events in man's time frame are recorded in years, or at most a life time, but natural events in the Arctic are recorded frequently in terms of centuries, because low temperatures tend to retard physical, chemical and biological forces. For example, partially preserved flesh of animals that roamed northern lands 20 to 50 thousand years ago have been recovered recently from permafrost. This means that solid waste placed in frozen ground can be a source of annoyance to many future generations of man (Alter 1972). Solid wastes apparently accumulate at a faster rate in cold regions than they do in temperate climates, presumably due to the fact that the frozen ground and prevailing low temperatures prevent normal breakdown and corrosion and also due to the fact that the life of many materials is greatly shortened by the effects of low temperatures with the result that material is discarded and replaced at more frequent intervals (Alter 1972).

In a study designed, in part, to evaluate the foreseeable effects of solid wastes generated by oil and gas development and pipeline construction, Grainge and co-workers (1973) estimated the quantity of solid wastes that would accrue in the form of broken machinery and equipment, concrete, rubble, waste oil and solvents, packaging debris, and various life support wastes. If one assumes a camp of 600 to 700 men, interpolation from various other arctic industrial activities suggests that there would be 540 to 675 kg per day of municipal type waste (office papers, packaging and cardboard, soda cans, kitchen cans and bottles), 90 to 225 kg per day of food scraps and cooking wastes, and 900 to 1,800 kg per day of garage repair shop wastes, consisting of metals, oils, solvents, wash down water, strapping, packaging, concrete and form lumber. This is a total of 1,800 to 2,700 kg per day of extremely diverse waste, excluding any route or campsite timber-clearing wastes. In addition, there will be broken equipment parts and other metals to be disposed of because of breakage from metal fatigue and lack of salvage markets within an economic haul distance. The 1,800 to 2,700 kg per day of material when properly smashed and compacted would consume 3.8 to 6.1 m^3 of burial space; overall a 380 to 760 m^3 disposal site would probably be required for a winter-long campsite of 600 to 700 men. This could be obtained by digging a trench 3.7 to 4.6 m wide, 3.0 to 4.6 m deep, and 30.5 to 45.7 m long (Grainge et al. 1973). In areas that have widespread occurrence of massive ground-ice, these trenching requirements are another possible source of terrain disturbance and subsidence. Furthermore, the most desirable trenching sites would be relatively ice-free coarse-textured materials such as eskers, and such sites are often in high demand for other land uses such as for mining of aggregate materials for construction purposes.

Ground disposal of liquid waste by lagooning involves uncertainties associated with the nature of the soil, the presence or absence of massive ice deposits nearby, and possible thermal erosion. While it is unlikely that a carefully sited and sensibly constructed lagoon will suffer from degradation, the fact remains that lagooning is essentially an uncontrolled process and that unforeseen difficulties are particularly hard to solve (Grainge et al. 1973).

If camps or temporary settlements associated with oil and gas development were to use as an alternative sewage treatment method the discharge of sewage into unprepared depressions or natural lakes (as is done in the case of some communities) there would be some detrimental environmental effects. Floating solids would be trapped by emergent vegetation and unsightly sludge banks would build up near the inlet (Grainge et al. 1973). The side effects of discharging raw or partially treated sewage to northern wetlands is the subject of continuing research at present (Government of Canada 1972a).

The increasing human population that will accompany widespread northern petroleum development and the increase of various support services will contribute indirectly to environmental loading with numerous compounds. For example, industrial applications of polychlorinated biphenyls (PCB) and various other halogenated hydrocarbons that are used as solvents, fumigants, refrigerants, flame retardants, aerosol propellants, heat-transfer media and hydraulic fluids have been documented by Zitko and Choi (1971). These same authors have also described recently determined PCB concentrations in various species of fish and aquatic birds. Although sewage outfalls and ocean dumped sludge are probably the main sources of PCB, industrial activity associated with northern petroleum development will also be a minor direct source of release of these compounds to the environment.

CONCLUSIONS

In the past five years there has been a great increase in petroleum exploration in the Canadian Arctic with all indications pointing to a further increase in the next several years. Associated with this has been an accelerated pace in related ecological research. Most of the research has been conducted in relation to the exploration phase yet with the intent of extrapolating these data to the development and transportation phases.

In the early stages of exploration, much of the ecological concern centered on terrain changes resulting from seismic activity and on inventories of vegetation, and animal populations including fish, birds and mammals along the proposed pipeline routes. Emphasis is now shifting to studies on the ecological requirements of major species so that their long-range management can be designed in relation to oil and gas field development and transportation facilities. Design of waste disposal facilities and contingency plans for oil or gas spill containment will probably take higher priorities in the future.

Of major concern now is the incorporation of ecological information into the design criteria, construction plans, and operational procedures of petroleum development. Until this is done, little more than lip service will have been paid to maintaining viable arctic ecosystems and alternative ways of life for northern native peoples. In addition, training courses for northern construction, supply, and operational crews will be essential if these huge operations are not to result in undesirable and unnecessary environmental modifications. Indications are evident from government and industrial groups that design criteria and construction plans are being modified in terms of ecological concerns and that training courses stressing the need for maintaining environmental quality will occur. Only the years ahead will show how successful we have been in blending engineering and ecological technology to achieve in a relatively pristine arctic what we have so consistently failed to do in the latitudes where we desire these fossil fuels. May the record show that the cooperative approach of government, industry and universities for environmental research and education has succeeded.

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