remained would work slowly or not at all in the dark and cold. If we kept walking, we would eventually stand in a country without the earthworm or the carrion beetle, a place where earth and decay are almost unknown, on the lifeless gravels of the polar desert.

Traveling north from the equator you could not help but notice, too, the emergence of recognizable seasons, periods of time characterized by conditions of rising, falling, or relatively stable light, in association with certain ranges of temperature. By the time you entered the Temperate Zone you would find a set of seasons distinct enough to be named and easily separated. Farther north, "spring" and "fall" would seem increasingly transitory, until each became a matter of only a few weeks. Winter, you would eventually find, lasted appreciably longer than summer. And together the two would define the final landscape.

The seasons are associated in our minds with the growth of vegetation. Outside of the four primary seasons (a constant referent with us, a ready and seemingly natural way to organize our ideas), we speak of a growing season and of a fallow season, when we picture the earth lying dormant. In the middle of an arctic winter, however, there is such a feeling of a stone crushed beneath iron that it is hard to imagine any organism, even a seed, living, let alone lying fallow. In summer, in the sometimes extravagant light of a July day, one's thoughts are not of growth, of heading wheat and yellowing peaches, but of suspension, as if life had escaped the bounds of earth. In this country, which lacks the prolonged moderations between winter and summer that we anticipate as balmy April mornings and dry Indian summer afternoons, in this two-season country, things grow and die as they do elsewhere, but they are, more deeply than living things anywhere else, seasonal creatures.

The trees are no exception. The northern limit of the continental forests in North America seems anomalous if you try to make sense of the tree line. The boundary sweeps southwest from Labrador to pass beneath James Bay, then turns northwest, cross-

ing Canada's Precambrian Shield and paralleling the Mackenzie River Valley nearly to the Arctic Ocean before zigzagging west through the valleys of the Brooks Range and the Kobuk River to Norton Sound. The explanation for the irregularity of the line lies with the seasonal climate—it marks the average southward extension of arctic air masses in summer.

The far northern trees, like the animals, constitute a very few species—willows growing in valleys where they are protected from the wind and a dwarf form of birch. Along the tree line itself, the only successful strategists are species in the pine and birch families. Their numbers thin out over a span of several miles, with trees persisting farther north in isolated patches where there is a fortuitous conjunction of perennially calm air, moisture, and soil nutrients. Islands of trees in the tundra ocean.

The growth of trees in the Arctic is constrained by several factors. Lack of light for photosynthesis of course is one; but warmth is another. A tree, like an animal, needs heat to carry on its life processes. Solar radiation provides this warmth, but in the Arctic there is a strong correlation between this warmth and closeness to the ground. In summer there may be a difference of as much as 15°F in the first foot or so of air, because of the cooling effect of the wind above and the ability of dark soils to intensify solar radiation. To balance their heat budgets for growth and survival, trees must hug the ground—so they are short. Willows, a resourceful family to begin with, sometimes grow tall, but it is only where some feature of the land stills the drying and cooling wind.

Lack of water is another factor constraining the development of trees. No more moisture falls on the arctic tundra in a year than falls on the Mojave Desert; and it is available to arctic plants in the single form in which they can use it—liquid water—only during the summer.

Permafrost, the permanently frozen soil that underlies the tundra, presents arctic trees with still other difficulties. Though they can penetrate this rocklike substance with their roots, deep roots, which let trees stand tall in a windy landscape, and

can draw water from deep aquifers, serve no purpose in the Arctic. It's too cold to stand tall, and liquid water is to be found only in the first few inches of soil, for only this upper layer of the ground melts in the summer. (Ironically, since the permafrost beneath remains impervious, in those few weeks when water *is* available to them, arctic trees must sometimes cope with boglike conditions.)

Trees in the Arctic have an aura of implacable endurance about them. A cross-section of the bole of a Richardson willow no thicker than your finger may reveal 200 annual growth rings beneath the magnifying glass. Much of the tundra, of course, appears to be treeless when, in many places, it is actually covered with trees—a thick matting of short, ancient willows and birches. You realize suddenly that you are wandering around on *top* of a forest.

VIRTUALLY all of the earth's biological systems are driven by solar radiation. As the light falls, so must the animals and plants arrange their growth and daily activities. The Arctic receives, strangely, the same amount of sunshine in a year as the tropics, but it comes all at once, and at a low angle of incidence—without critical vigor. The regular rhythm of light-fall in the tropics, that predictable daily infusion of energy, together with its high angle of incidence, are the primary reasons for the natural stability of these ecosystems. The rainy season aside, temperature and humidity on a day in May are not so different from temperature and humidity on a day in December. The animals and plants have evolved breeding and feeding strategies, of course, that depend on this almost uninterrupted flow of light.

In the Temperate Zone, periods of daily light-fall are not equal during the year. The animals and plants must adjust to a seasonal way of life. In the Arctic this situation becomes much more extreme. Periods of light-fall can't readily be divided into days. The average temperature fluctuates over a period of 365 days, not twenty-four hours; sources of water are frozen; and the dim light puts a special burden on animals that must use their eyes to search. The very rhythm of light itself creates a difficulty. Most animals

live lives in biological keeping with the earth's twenty-four-hour period of rotation. They have neither the stamina nor the flexibility, apparently, to adapt to the variable periods of light they encounter in the Arctic's nightless summer and dayless winter.*

The adaptive strategies of arctic animals to failing light and low temperatures are varied. In general, they must either develop insulation against the cold or slow down, or halt, their metabolic processes to survive. Warm-blooded animals and flowering plants aside (these must bloom and fruit rapidly in the summer), the most salient, overall adaptive strategy of arctic organisms is their ability to enter a frozen state or a state of very low metabolic activity whenever temperatures drop, and then to resume full metabolic activity whenever it warms sufficiently. Many arctic spiders and insects, along with lichens, ferns, and mosses, lie frozen for the duration of winter. Trees, along with grizzly bears and ground squirrels, carry on their life processes but at a very low metabolic rate. Fish and various beetles use cellular antifreeze agents (glycoproteins) to extend their periods of activity during freezing weather. Other adaptive strategies show parallels with those of desert plants. The leathery leaves of saxifrages and the hairy leaves of Labrador tea, for example, both reduce the transpiration of precious water in the short summer.

Slowing down their rate of growth is another strategy cold-blooded animals use. The scant solar energy available to them in the summer is often not enough to complete their development from larval to adult stages, so they must "plan" not to be at a vulnerable point of transition just as winter is coming on. Other strategies to take advantage of short periods of light for growth

* A few arctic animals, possibly auks and other nonpasserine birds, for example, might be "free-running." The rest maintain a twenty-four-hour rhythm, which they synchronize without the benefit of a sunrise or a sunset. Some, apparently, regularly mark the position of the sun over a certain landmark, or respond to fluctuations in the spectral composition (color temperature) of sunlight, which in the Arctic is different at midnight from what it is at noon.

and sustenance include the winter carryover of evergreen leaves by the dwarf birch (so it does not have to grow leaves again in the spring to begin photosynthesis); and the very large yolks of arctic cod eggs, which give these embryos a nutritional head start before the return of light in the spring triggers a bloom of plankton, their principal food when they hatch. With this head start they are larger and stronger and better able to survive when the ocean begins to freeze over in the fall.

Scientists believe tropical ecosystems are the oldest ones on earth. Compared with northern ecosystems, where development has been periodically halted or destroyed by the advance of glaciers, they have had many more thousands of years of undisturbed biological evolution. They are also characterized by a special kind of biological stability not found in the North—the finite number of individuals in any given tropical species hardly varies through time. This biological stability is linked to the stability of the climate and is perpetuated by highly intricate food webs and high rates of biological production. Many species, producing many young, exploit a very large number of biological niches. The system is practically invulnerable to most natural disturbances, such as a disease that might wipe out every one of a certain kind of tree. It is too diversified to be affected.

Some biologists believe all ecosystems tend to develop in the direction of stability, that is, toward many types of animals (great species diversity) and very small population surges and declines. Temperate-zone and arctic ecosystems, according to this view, are slowly evolving toward the kind of diversity and stability one sees in the tropics. But they are not liable to develop the complex food webs of the tropics, that kind of resilient diversity, on any scale of time in which we are used to thinking. The northerly ecosystems must contend with significant fluctuations in the amount of solar energy received; their rate of biological evolution, therefore, is much slower. In addition, the northerly ecosystems regularly experience severe biological disturbances related to normal weather patterns (the "unseasonable weather" blamed for the loss of a

citrus crop in Florida or the early emergence of hibernating bears in Montana). Arctic climatic patterns are further characterized by unpredictable and violent weather.

The communal alliances of far northern plants and animals we call ecosystems are distinguished from more southerly ecosystems by larger biomasses and lower overall productivity. Instead of many species, each with relatively few individuals in it, we find relatively few species, each with many individuals—large herds of caribou, for example, or vast swarms of mosquitoes. But, generally speaking, these large populations do not include enough surviving young each year to keep their populations stable. The size of the population often changes, dramatically, as a matter of course; the violent weather typical of early and late summer routinely wreaks havoc on some arctic populations, particularly those of warm-blooded animals. On Wrangel Island in the Siberian Arctic, for example, an unbroken, ten-year series of late spring snowstorms prevented lesser snow geese from ever laying their eggs. Between 1965 and 1975 the population fell from 400,000 to fewer than 50,000 birds. In different years in the Greenland Sea where harp seals pup on the ice floes, spring storms have swept hundreds of thousands of infant harp seals into the sea, where they have drowned. In the fall of 1973, an October rainstorm created a layer of ground ice that, later, muskoxen could not break through to feed. Nearly 75 percent of the muskox population in the Canadian Archipelago perished that winter.

Biologists, for these mostly climatological reasons, characterize arctic ecosystems as "stressed" or "accident-prone," underscoring the difference between them and temperate and tropical ecosystems. With their milder climates and longer growing seasons the latter are more forgiving. In the South, the prolongation of spring permits birds to lay two or even three clutches of eggs if the first is destroyed by predation or adverse weather. An arctic nester, by comparison, has only a short period of solar energy available, which it must take swift and efficient advantage of for rearing its young, laying on reserves of fat for its southward journey, and accomplishing its

own molt, a fatiguing process that its southern relatives can spread out over several months. (The solar energy upon which it is dependent, of course, is producing more than warmth and light. It is melting water to drink, fueling photosynthesis in the bird's food plants, and bringing to life the insects upon which it depends for protein.)

Because arctic nesters must face unpredictable weather along with an abbreviated period of solar energy, the timing of their arrival on the nesting ground and of their egg-laying and departure is critical. When a June sleet storm or a sudden August freeze destroys an entire generation of young birds, or 10,000 seals, or hundreds of caribou calves, it comes home in the starkest way that this is an environment marked by natural catastrophe, an inherently vulnerable ecosystem. The stress apparent to us, however, is not a sign of any weakness or fragility in arctic ecosystems. In fact, they show a remarkable resiliency. The Canadian muskox population increased dramatically after the winter of 1973–74. The harp seal thrives today in the Greenland Sea. The population of snow geese on Wrangel Island was back to about 300,000 by 1982.*

If we finally stood, then, at the end of our journey, looking over the tundra with that short list of arctic creatures to hand, wondering why it had dwindled so, we would need to look no further than that yellow star burning so benignly in the blue summer sky. It is the sunlight, always the streaming sunlight, that matters most. It is more critical even than temperature as a limiting factor on life. The salient reason there are so few species here

*The operation of the biological mechanisms responsible for the recovery of arctic species remains largely mysterious. Current research, however, indicates that, unlike their temperate-zone counterparts, arctic animals are apparently unable to tolerate both the inherent stress to which, in an evolutionary sense, they are accustomed and new stresses of man-made origin—oil blowouts, pollution from mine tailings, noise from arctic shipping, and the unnatural patterns of sea-ice disruption associated with icebreakers. They are therefore probably more vulnerable to man-made intrusions than the populations of any animals we have ever dealt with.

is that so few have metabolic processes or patterns of growth that can adapt to so little light. (Secondarily, many warm-blooded creatures can't conserve enough heat to survive in the extreme cold.) Of the roughly 3200 species of mammal we could possibly have encountered on the way north, we would find only 23 or so living beyond the tree line in this cold, light-poor desert.* Of some 8600 species of birds, only six or seven—common raven, snowy owl, rock ptarmigan, hoary redpoll, gyrfalcon, Ross's gull, and ivory gull—overwinter in the high Arctic, and only about 70 come north to breed. Of the boundless species of insect, only about 600 are to be found in the Arctic.† Of perhaps 30,000 species of fish, fewer than 50 have found a way to live here.

In certain parts of the Arctic—Lancaster Sound, the shores of Queen Maud Gulf, the Mackenzie River Delta, northern Bering Sea, the Yukon-Kuskokwin Delta—great concentrations of wildlife seem to belie violent fluctuations in this ecosystem. The Arctic seems resplendent with life. But these are summer concentrations, at well-known oases, widely separated over the land; and they consist largely of migratory creatures—geese, alcids, and marine mammals. When the rivers and seas freeze over in September they will all be gone. The winter visitor will find only caribou and muskoxen, and occasionally arctic hares, concentrated in any number, and again only in a few places.

All life, of course, cannot fly or swim or walk away to a warmer climate. When winter arrives, these animals must dis-

* Grizzly bear, polar bear, short-tailed weasel (ermine), least weasel, mink, wolverine, coyote, wolf, red fox, arctic fox, hoary marmot, arctic ground squirrel, collared lemming, brown lemming, tundra red-back vole, tundra vole, Alaska vole, porcupine, arctic hare, tundra hare, moose, caribou, muskox.

† They include about 175 species of parasitic wasp, 25 species of sawfly, 40 species of moth, 100 species of root maggot, and 150 species of midge, as well as smaller numbers of species of black and crane flies, blowflies, hover flies, bumblebees, mosquitoes, springtails, fleas, butterflies, and about 60 species of beetle.

perse to areas where they will have a good chance to find food and where there is some protection from the weather. A few hibernate for seven or eight months. Voles and lemmings go to ground too, but remain active all winter. Wolves shift their home ranges to places where caribou and moose are concentrated. Arctic foxes follow polar bears out onto the sea ice, where they scavenge the bear's winter kills. Arctic hares seek out windblown slopes where vegetation is exposed. All these resident animals have a measure of endurance about them. They expect to see you, as unlikely as it may seem, in the spring.

In my seasonal travels the collared lemming became prominent in my mind as a creature representative of winter endurance and resiliency. When you encounter it on the summer tundra, harvesting lichen or the roots of cotton grass, it rises on its back feet and strikes a posture of hostile alertness that urges you not to trifle. Its small size is not compromising; it displays a quality of heart, all the more striking in the spare terrain.

Lemmings are ordinarily sedentary, year-round residents of local tundra communities. They came into the central Arctic at the end of the Pleistocene some 8000 years ago, crossing great stretches of open water and extensive rubble fields of barren sea ice to reach the places they live in today. In winter lemmings live under an insulating blanket of snow in a subnivean landscape, a dark, cool, humid world of quiet tunnels and windless corridors. They emerge in spring to a much brighter, warmer, and infinitely more open landscape—where they are spotted by hungry snowy owls and parasitic jaegers and are hunted adroitly by foxes and short-tailed weasels. In most years, in most places, there is not much perplexing about this single link in several arctic food chains. In some places, every three or four years, however, the lemming population explodes. Lemmings emerge from their subnivean haunts in extraordinary numbers and strike out—blindly is the guess—across the tundra.

The periodic boom in lemming populations—there are comparable, though more vaguely defined, cycles affecting the periodic

rise and fall of snowshoe hare and lynx populations, and caribou and wolf populations—is apparently connected with the failure of the lemmings' food base. The supply of available forage reaches a peak and then collapses, and the lemmings move off smartly in all directions as soon as traveling conditions permit in the spring. Occasionally many thousands of them reach sea cliffs or a swift-moving river; those pushing in the rear force the vanguard into the water to perish.

Arctic scientist Laurence Irving, camped once on a gravel bar off the Alaska coast, wrote: "In the spring of a year of climaxing abundance, a lively and pugnacious lemming came into my camp . . . [more] tracks and a dead lemming were seen on the ice several kilometers from shore. The seaward direction of this mad movement was pointless, but it illustrates stamina that could lead to a far dispersal." Irving's regard, of course, is a regard for the animal itself, not for the abstract mechanisms of population biology of which it seems to merely be a part. Its apparently simple life on the tundra suggests it can be grasped, while its frantic migrations make it seem foolish. In the end, it is complex in its behavior, intricately fitted into its world, and mysterious.

Whenever I met a collared lemming on a summer day and took its stare I would think: Here is a tough animal. Here is a valuable life. In a heedless moment, years from now, will I remember more machinery here than mind? If it could tell me of its will to survive, would I think of biochemistry, or would I think of the analogous human desire? If it could speak of the time since the retreat of the ice, would I have the patience to listen?

One time I fell asleep on the tundra, a few miles from our camp. I was drowsy with sun and the weight of languid air. I nestled in the tussock heath, in the warm envelope of my down parka, and was asleep in a few moments. When I awoke I did not rise, but slowly craned my head around to see what was going on. At a distance I saw a ground squirrel crouched behind a limestone slab that rose six or eight inches out of the ground like a wall. From its attitude I thought it was listening, confirming the presence

of some threat on the other side of the rock, in a shallow draw. After a while it put its paws delicately to the stone and slowly rose up to peer over, breaking the outline of the rock with the crown of its head. Then, with its paws still flat at the rim, it lowered itself and rested its forehead on the rock between its forelegs. The feeling that it was waiting for something deadly to go away was even stronger. I thought: Well, there is a fox over there, or a wolverine. Maybe a bear. He'd better be careful.

I continued to stare at him from the warm crevice in the earth that concealed me. If it is a bear, I thought, I should be careful too, not move from here until the ground squirrel loses that tension in its body. Until it relaxes, and walks away.

I lay there knowing something eerie ties us to the world of animals. Sometimes the animals pull you backward into it. You share hunger and fear with them like salt in blood.

The ground squirrel left. I went over to the draw beyond the rock but could find no tracks. No sign. I went back to camp mulling the arrangements animals manage in space and in time—their migrations, their patience, their lairs. Did they have intentions as well as courage and caution?

Few things provoke like the presence of wild animals. They pull at us like tidal currents with questions of volition, of ethical involvement, of ancestry.

For some reason I brooded often about animal behavior and the threads of evolution in the Arctic. I do not know whether it was the reserves of space, the simplicity of the region's biology, its short biological history, striking encounters with lone animals, or the realization of my own capacity to annihilate life here. I wondered where the animals had come from; and where we had come from; and where each of us was going. The ecosystem itself is only 10,000 years old, the time since the retreat of the Wisconsin ice. The fact that it is the youngest ecosystem on earth gives it a certain freshness and urgency. (Curiously, historians refer to these same ten millennia as the time of civilized man, from his humble beginnings in northern Mesopotamia to the present. Arctic eco-

systems and civilized man belong, therefore, to the same, short epoch, the Holocene. Mankind is, in fact, even older than the Arctic, if you consider his history to have begun with the emergence of Cro-Magnon people in Europe 40,000 years ago.)

Human beings dwell in the same biological systems that contain the other creatures but, to put the thought bluntly, they are not governed by the same laws of evolution. With the development of various technologies—hunting weapons, protective clothing, and fire-making tools; and then agriculture and herding—mankind has not only been able to take over the specific niches of other animals but has been able to move into regions that were formerly unavailable to him. The animals he found already occupying niches in these other areas he, again, either displaced or eliminated. The other creatures have had no choice. They are confined to certain niches—places of food (stored solar energy), water, and shelter—which they cannot leave without either speciating or developing tools. To finish the thought, the same technological advances and the enormous increase in his food base have largely exempted man from the effect of natural controls on the size of his population. Outside of some virulent disease, another ice age, or his own weapons technology, the only thing that promises to stem the continued increase in his population and the expansion of his food base (which now includes oil, exotic minerals, fossil ground water, huge tracts of forest, and so on, and entails the continuing, concomitant loss of species) is human wisdom.

Walking across the tundra, meeting the stare of a lemming, or coming on the tracks of a wolverine, it would be the frailty of our wisdom that would confound me. The pattern of our exploitation of the Arctic, our increasing utilization of its natural resources, our very desire to "put it to use," is clear. What is it that is missing, or tentative, in us, I would wonder, to make me so uncomfortable walking out here in a region of chirping birds, distant caribou, and redoubtable lemmings? It is restraint.

Because mankind can circumvent evolutionary law, it is incumbent upon him, say evolutionary biologists, to develop another

law to abide by if he wishes to survive, to not outstrip his food base. He must learn restraint. He must derive some other, wiser way of behaving toward the land. He must be more attentive to the biological imperatives of the system of sun-driven protoplasm upon which he, too, is still dependent. Not because he must, because he lacks inventiveness, but because herein is the accomplishment of the wisdom that for centuries he has aspired to. Having taken on his own destiny, he must now think with critical intelligence about where to defer.

A Yup'ik hunter on Saint Lawrence Island once told me that what traditional Eskimos fear most about us is the extent of our power to alter the land, the scale of that power, and the fact that we can easily effect some of these changes electronically, from a distant city. Eskimos, who sometimes see themselves as still not quite separate from the animal world, regard us as a kind of people whose separation may have become too complete. They call us, with a mixture of incredulity and apprehension, "the people who change nature."

I remember one summer evening on the sea ice at the mouth of Admiralty Inlet, lying on caribou skins in my tent, nursing a slight wound I had suffered during the butchering of a narwhal. I was one of two white men in the group of eight and the only one who did not speak Inuktitut, which, far out on the sea ice, increased my feelings of isolation. As I lay there, however, I recalled vaguely some words of Wilfred Thesiger, who traveled among the Bedouin, which I later looked up: "I was happy in the company of these men who had chosen to come with me. I felt affection for them personally and sympathy with their way of life. But though the easy quality of our relationship satisfied me, I did not delude myself that I could be one of them. They were Bedu and I was not; they were Muslims and I was a Christian. Nevertheless I was their companion and an inviolable bond united us."

Lying there in the tent, I knew, as does everyone I think who spends some time hunting with Eskimos, that they are not idyllic

people, errorless in the eyes of God. But they are a people, some of them, still close to the earth, maintaining the rudiments of an ancient philosophy of accommodation with it that we have abandoned. Our first wisdom as a species, that unique metaphorical knowledge that distinguishes us, grew out of such an intimacy with the earth; and, however far we may have come since that time, it did not seem impossible to me that night to go back and find it. I wanted to enquire among these people, for what we now decide to do in the North has a certain frightening irrevocability about it.

I wanted to enquire, as well, among thoughtful visitors, people who were taken with the land. Each culture, it seemed to me, is a repository of some good thought about the universe; we are valuable to each other for that. Lying there, I thought of my own culture, of the assembly of books in the library at Alexandria; of the deliberations of Darwin and Mendel in their respective gardens; of the architectural conception of the cathedral at Chartres; of Bach's cello suites, the philosophy of Schweitzer, the insights of Planck and Dirac. Have we come all this way, I wondered, only to be dismantled by our own technologies, to be betrayed by political connivance or the impersonal avarice of a corporation?

I had no idea as I lay on those caribou skins that evening precisely where wisdom might lie. I knew enough of quantum mechanics to understand that the world is ever so slightly but uncorrectably out of focus, that there are no absolutely precise answers. Whatever wisdom I would find, I knew, would grow out of the land. I trusted that, and that it would reveal itself in the presence of well-chosen companions.

I looked out of the tent. It was after one in the morning. A south wind blew, but so slightly. The kind of wind nineteenth-century sailors called "inclinable to calm." Nakitavak lay stretched out on caribou skins and a cotton sleeping bag on his big sled, his qamutiik, watching the still black water between two massive ice floes, the open lead into which narwhals would come, sooner or later. His brother David, both hands wrapped around a mug of tea, was looking to the west, the direction from which he thought they

would come. His lips stretched to the steaming, hot surface of the tea, and in the chill air I heard the susurrations of his sipping.

These Tununiarusirmiut men, relatives of the Tununirmiut to the east who had met the whalers 160 years ago, knew beyond a shadow of a doubt, beyond any hesitation, what made them happy, what gave them a sense of satisfaction, of wealth. An abundance of animals.

And so, we waited.