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HUMAN ADAPTATION TO ARCTIC ZONES

Emilio F. Moran

Department of Anthropology, Indiana University, Bloomington, Indiana 47401

INTRODUCTION

The study of human adaptation to polar areas has engaged scholars in many fields since the late nineteenth century. The first two scientific monographs on the Eskimo were published in 1888 (16,55), and were soon followed by useful reports (2, 39, 99, 110). Since then much work has been undertaken, and efforts at a synthesis are now under way. Tundra ecosystems were recently a focus of research efforts by the International Biological Program (IBP), and students with interest in the human ecology of this region now have a rich and rapidly growing literature. The Swedish component of the IBP/Tundra Biome has published a useful collection of papers on the structure and function of tundra ecosystems (102).

Hildes (53) and Laughlin (75) summarized knowledge of arctic human ecology, and the synthesis volume from the human adaptability component of the US/IBP (66) updates and fills in many of the gaps identified earlier by Hildes (53) and Laughlin (75). The annotated bibliography by Culver (30) is outdated but still useful. Important discussions on the methodology of studying human adaptability to cold stress are presented by Yoshimura & Weiner (119) and Weiner & Louri (117). Important surveys of human adaptation to cold are those by Folk (42), Carlson & Hsieh (29), Edholm & Lewis (38), Van Wie (113), and Little & Hochner (81). The latter approaches the problem of thermal stress with an emphasis on growth and development. The best recent syntheses of tundra ecology are by Bliss et al (15) and Brown et al (17a).

In this review I shall concentrate on human social and cultural adaptive strategies as they are applied to High Arctic populations. At appropriate places the reader will be referred to relevant biological adaptations treated

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by Joseph So in last year's volume of the *Annual Review of Anthropology* (106a). All too often anthropological discussions remain isolated from each other, and a holistic view of human adaptation is thereby impeded. This review focuses not on a set of social/cultural mechanisms, but rather on the fundamental problems faced by populations in the Arctic and their adjustments to them. The basis of such human adaptability and the various multiple-level responses to these constraints are discussed in a recent volume by this author (87).

Social and cultural anthropologists have attempted syntheses since research began (e.g. 3, 16, 110). Among the more notable recent efforts are those by Birket-Smith (13), Spencer (107), Osburn (95), Gubser (46), Graburn & Strong (45), and Chance (28). Nelson (93) provided a finely detailed description of hunting behavior, as did Balikci (5). Damas (32, 33) undertook a comparative study of central Eskimo society using a cultural ecological approach. Lantis (73) has produced the most detailed descriptions of Eskimo religion and ceremonial life. These studies may now be integrated to human bioecological considerations through the efforts of the human adaptability section of the IBP.

The US/IBP research available to date on the High Arctic also suggests directions along which comparative studies can be made with other arctic regions. The contrast with regions such as the Aleutian Islands is striking and suggests that we have only begun to understand the numerous factors that are involved in arctic human adaptations (52, 74, 78). These contrasts in resources and exploitative means will be brought to the reader's attention throughout this review. Discussion of the antarctic region has been omitted because the inhabitants there are temperate zone dwellers transported to Antarctica for short periods of time, after which they return to warmer climates. Research on the adaptability of these temporary human inhabitants has been reported by Budd (19) and Natani & Shurley (92).

There is solid evidence that human occupation of arctic zones began between 8,000 and 15,000 B.P., when hunters from Siberia crossed the Bering land bridge (7, 56). However, there is indirect evidence that migrations may have occurred as early as 28,000 B.P. (61, 89). Laughlin (79) suggests that present-day Eskimos and Aleuts are both derived from a common sea-oriented Mongoloid population. According to Laughlin (79), those reaching Nikolski Bay became Aleuts, while those who migrated farther north became Eskimos. McGhee (86) discusses the occupation of Arctic North America. Fitzhugh (4) has given us an unusually useful work on comparative prehistory across the Arctic.

The High Arctic's extreme and prolonged cold makes plants so low in productivity that human populations have had to rely primarily on the consumption of animals that do not live year-round in the arctic tundra. In

addition to the cold stress to which populations are potentially exposed, the Arctic constrains human occupation because of seasonal extremes of light and darkness, snow cover for two-thirds of the year, and low biological productivity. Human adaptation to arctic zones requires a measure of psychological accommodation, physiological acclimatization, developmental adaptation, and cultural adaptation. The situation is even harsher in Antarctica. The Antarctic continent covers 14.24 million square kilometers, of which only 10,350 km^2 is estimated to be suitable for sustaining life. The largest permanent inhabitant is a tiny fly. There are no land vertebrates, no birds, no amphibians, no reptiles, no freshwater fish, no mollusks, and no earthworms. Only lichens, mosses, and fungi in protected coastal areas are able to exist (92, pp. 90–91).

Like other biomes, the tundra is not wholly undifferentiated. From the margins of the boreal coniferous forest, or *taiga,* to the polar desert, one may note at least three types of tundra vegetation. The "bush tundra" represents the ecotone that borders the taiga and is characterized by dwarf trees. The bush tundra grades off into the broader expanse of "grass tundra," composed of a nearly continuous mat of mosses, lichens, and bushes that tend to lie flat on the ground. When the soil surface thaws out in summer, the water does not drain but is soaked by the spongy vegetation. Closer to the poles is the "desert tundra," an area characterized by lack of vegetation, except in protected hollows (64, p. 362). These differences are associated with the depth at which permafrost begins. The depth of thawing may vary from only a few inches to a depth of about 2 feet. Below this the ground will remain frozen and impermeable to both water and plant roots (112). Tundra soils may contain high accumulations of peaty organic matter caused by the slow breakdown of plant material. The volume by Tedrow (111) is a definitive reference on arctic soils.

In all, tundra occupies about 8 million square kilometers of land or one-twentieth of the earth's land surface (116). To date, it is an area with a sparse population—i.e. between 2 and 18 persons per 100 km^2. In 1972 there were 95,000 Eskimos scattered in Greenland, Canada, Alaska, and Siberia (120).[1] In addition, several Eurasian peoples inhabit the Arctic, of which the Lapps, Samoyeds, Yakuty, and Chukchi are the most numerous (60, p. 23). The most comprehensive studies of Eskimo groups are those by Spencer (107) and Oswalt (96), both of which emphasize that cultural distinctions in Eskimo life-styles are the result of ecological adjustments to

[1]Eskimo populations are difficult to divide into unambiguous subgroups because of contradictory linguistic, cultural, and biological evidence. Zegura (120) discusses the various boundaries offered by these three perspectives. Krauss (70) summarizes the linguistic evidence, Spencer (107) the cultural basis, and Laughlin (79) the recent archaeological evidence.

coastal or inland resources. Spencer (107) divided the Eskimo populations into *nunamiut* (people of the land) and *taremiut* (people of the sea) in accordance with the predominant subsistence strategy.[2] Other ethnographers have noted that both groups tended toward endogamy (26) as a result of the specialization required to exploit the inland or the maritime resources (22, p. 24). The inland adaptation, based on caribou hunting, ended for a brief period in the 1920s and more definitively in the 1950s. In the 1920s, the outmigration was caused by shifts in caribou migratory routes, while in the 1950s, new weapons and overhunting reduced the size of the herd to the point where the human population could no longer be sustained (46; 104, p. 183; 107, p. 28). Since then, inland Eskimos have joined the maritime Eskimos in increasingly larger and fewer coastal villages (4, 65).

Tundra ecosystems are heat-limited ecosystems (15, 17a). As a result, there is low species diversity, low productivity,[3] and relatively insignificant plant succession. The short growing season in the Arctic inhibits levels of production capable of supporting a large herbivorous population. Tundra and desert ecosystems share comparably low primary productivity (54, 84). The crucial difference between them is that one is limited by water availability and the other by extreme cold.

Plants have numerous physiological adaptations to cope with arctic conditions: prolonged seed dormancy and rapid germination, vegetative reproduction, and metabolic systems able to capture, store, and use energy in a short time (11, p. 417). A large proportion of the plant biomass is below ground, protected from arctic wind, cold, and herbivore pressure (116, p. 457). The environment has been described as fragile because of these same characteristics. Alterations in plant cover reduce both surface insulation and albedo; more heat is absorbed, leading to deeper thaw and greater erosion. Erosion is difficult to control because of the slowness of plant succession. Once an eroded niche becomes emptied, there are few species that can occupy it because of the low species diversity (15, pp. 360–61). Arctic soils are of recent origin and tend to be hydromorphic. Most of the soil nutrients are not available for plants because of permafrost. To survive, therefore, plants use complex internal cycles that retain and reincorporate nutrients rather than relinquish them to the decomposers (20, p. 117). Phosphorus appears to be a limiting factor to arctic plants' productivity (20).

Many of the land animals such as reindeer (in Eurasia) and caribou (in North America) migrate over vast expanses of tundra territory in summer

[2]Oswalt (96) has referred to these two groups as "tribes," but few have followed this suggestion.

[3]Mosses yield the highest proportion of total phytomass, followed by phanerogams and lichens (84).

and exploit the richer boreal forests to the south [i.e. the taiga (41)]. Caribou and reindeer are essential resources to the inland arctic populations, as documented by Gubser (46), Balikci (5), and Arima (4). Herding, specifically reindeer herding, is about the only other effective way of supporting human populations in the inland tundra areas [(67, p. 219); see also recent studies of reindeer herding and its modernization by Pelto (97), Ingold (57, 58), and Müller-Wille (90)]. Smaller fauna are found in greater densities. Insects are restricted to a few genera but are abundant in midsummer. Black flies, deer flies, and mosquitoes are so numerous that Eskimos in many areas must continue to cover most parts of their bodies, despite the pleasant temperatures, to avoid their bites.

Arctic birds have a fast life cycle, similar to that for rodents. The ptarmigan and the redpoll have heavy layers of fat and dense feathers for cold protection. Most bird and insect species, however, leave the tundra for more southern regions as winter approaches. More important to the arctic human population has always been the ocean fauna. Ringed seals (*Phoca foerida*), barbed seals (*Erignathus barbatus*), walruses (*Odobenus*), whales (especially bowhead, white, and fin types), and fish and shellfish varieties are among the most important maritime resources exploited. Seals provide many raw materials that make Eskimo cold adaptation possible, such as mittens, boots, summer coats, trousers, and sinew thread. Coastal Eskimos rely for up to 83% of subsistence on marine and freshwater aquatic resources rather than terrestrial production. The inland population relies on a more even seasonal exploitation of both aquatic and terrestrial animals.

ADAPTATION TO COLD STRESS

Temperatures, particularly summer temperatures, are commonly mentioned as the defining characteristic of tundra biomes. The most commonly used is Köppen's boundary line of the 50°F (10°C) isotherm for the warmest month of the year (51, 64). However, other factors besides actual temperature are involved in tundra climate. Throughout the Arctic, tundra areas can be found which lie south of the 50° isotherm (82). For example, wind is important in the Arctic, not because it is strong, but because the absence of trees reduces the drag force at the earth's surface and the velocity profile near the ground can be very steep (82). The wind chill factor and consequent danger of frostbite and dehydration can be severe and constitutes one of the critical problems for human populations (24, 27, 37, 38, 59, 81, 113).

Eskimo adaptations to cold stress are both physiological and cultural. One common misconception has been that Eskimos have a great deal of body fat, when in reality Eskimos are relatively lean (75). Other common

morphological characteristics offer inadequate protection (31, 106a, 108, 109). Laughlin notes that the frequent use of—and need for—slit goggles and visors during travel is evidence for the inadequacy of morphological adaptations (75). Failure to protect against cold stress can result in cold injury, frostbite, hypothermia,[4], and eventually death (24, p. 16). Among the cultural practices that facilitate Eskimo adaptation to cold are clothes, shelter, use of seal oil lamps, sharing of body heat, and diet. Recent writings have described the exposure of Eskimos to the arctic cold as chronic and moderate. In fact, the microclimate of men in arctic clothing is the same as that of men working in temperate zones in light clothing. Exposure to cold then occurs primarily in the more exposed areas of the face and the extremities (42, p. 101).

One of the important ways to prevent cold stress is by providing for adequate insulation. The problem is dual: how to provide for continued warmth and, while dissipating heat, how to prevent overheating during periods of strenuous work. If the latter problem is not properly solved, sweat-soaked or frozen insulated clothing would result in a loss of its cold protection effectiveness. That this sometimes occurs has been noted by Irving (60). He describes how Eskimos hang their clothes to freeze and then beat out the frost with a stick. Eventually they must scrape the leather to restore its pliability.

Two methods are commonly used to regulate heat buildup. In summer, when Eskimos must do heavy work they take off their impermeable "outside" parka and remain relatively cool from the outside temperature.[5] More important, however, is the actual design of the Eskimo clothing. The traditional clothing of the Arctic has many vented openings through which air can flow constantly in and out by the releasing or closing of drawstrings (42, p. 123). This is one way in which traditional Eskimos adapted clothing to ambient conditions. The other major factor is that clothing has always been characterized by numerous layers in which trapped air acts as an insulator and, with the outside layer being windproof and impermeable, holds the heat in and cold and wetness out (39).

Boots (*kimik*) call for special attention. The sharp ice at subzero temperatures can cut the best footgear, and extreme care must be taken to protect such clothing. The soles are made of carefully prepared bearded seal skin. They are sewn with sinew, but the sewer avoids making needle holes all the

[4]Failure of the thermoregulatory system occurs when body core temperature is near 33°C, and death occurs at 25°C (27, p. 16).

[5]Another author noted that because of the difficulty of matching activity and weather to clothing while on the move, it is common to tolerate moderate degrees of thermal discomfort (17). The solution is to dress too warm and to tolerate sweating during work and shivering during rest periods.

way through the skin layers to assure its waterproofness. Stockings are made from the fragile fur of the arctic hare and are kept dry by inserting a pad of dry grass between the sole of the boot and the sole of the stocking. This pad absorbs any moisture that penetrates from outside or moisture from foot perspiration (39). Similarly, seakskin mittens have been filled with grass pads to protect the hands on long trips.

Because no clothing is perfect in design, Eskimos must rely on some behavioral adaptations to protect them from cold injury. The most difficult area to protect in travel is the exposed surface of the face. Warm hands are applied to the face when a sharp stinging sensation is felt. Hunting partners will warm each other's faces in this manner. Wiping mucus from the nose over areas manifesting signs of incipient frostbite has been noted (93, pp. 106–10).

Like clothing, Eskimo shelters must hold heat in and be waterproof. While engaged in nomadic activities in the pursuit of subsistence, Eskimos build snow shelters. Snow shelters (i.e. igloos) have been described as excellent insulators because of the myriad small air cells in the ice. The essential seal oil lamp provides the interior light and heat. The lamp causes minor melting of the inside snow surfaces which refreeze during the night, thus forming a smooth reflecting surface that conserves radiant heat. The outside surface becomes encrusted with snow and forms an airtight seal. In summer *tupik* or sealskin tents are utilized. The tents, made of dark-colored skins to absorb solar energy, are double layered and provide a comfortable temperature in the warmer periods (39). The tupik is made of many sealskins sewn into a continuous cover, with large tents requiring well over 60 skins. An inner tent and an outer tent create an area of dead air which facilitates warming during cold periods but can be opened during the summer months (39). For more permanent habitation, High Arctic Eskimos also build semisubterranean stone or driftwood housing covered with turf and snow for insulation. These are frequently located in protected hillside spots. Like clothing, the stone igloo always has ventilation holes to allow circulation and prevent overheating. The interiors are also covered with sealskins. Thus constructed, the subterranean home of winter is warm, keeping temperatures between 15.5° and 21°C (39).

While clothing and shelter help regulate exposure to cold and provide warm microclimates for humans, the Eskimos are exposed to extreme cold during winter seal hunting and ice fishing (72). In order to maintain body core temperatures within a permissible range, a number of systems may be activated. Of these the most important are regulatory shivering, vasoconstriction, increased basal metabolic rates (BMR), and increased oxygen consumption [see (106a) for a detailed discussion of physiological and biochemical adjustments (see also 71)]. The evidence on physiological ad-

justments does not suggest a general adaptation to cold by Eskimos and other arctic natives. This may be due to the excellent protection provided to the body by the cultural adjustments that prevent exposure of the body core (38, 42, 48–50, 81).

COPING WITH SNOW AND SEA ICE

A great deal of the ecological knowledge of Eskimos centers around the identification of minute differences in ice and snow characteristics. Eskimo children learn experimentally to identify these differences because of their survival value. Collier (29) has described Eskimo traditional education as nonverbal and ecological—facilitating weather prediction, recognition of blizzard warnings, and migratory patterns of game. The best description of the hunting behavior of Eskimos in northwest Alaska is that by Nelson (93), who looks at hunting behavior in an ethological-ecological sense.

Laughlin (76) views the training of a hunter as a biobehavioral system in which the child is programmed into habits of observation, systematic knowledge of animal behavior, and appropriate use of the game for food and other needs. Because hunted animals are often endowed in hunting cultures with spirits or souls, the hunt may be a hazardous period. Thus, the child is taught to have respect for hunting and the prey, to scan, stalk, immobilize, retrieve, and share his fortune with others. The technology of most traditional Eskimo hunters requires that they get close to their prey. How to achieve this represents a lengthy investment in childhood and young adult education. Adults sometimes capture animals to serve as instruction in animal habits and anatomy. Play-acting and sports-like events are given an educative content valuable in the hunt (28, p. 74). Perseverance and toughness are particularly desirable traits (93, pp. 375–76). Generosity, particularly toward kin and meat-sharing nonrelatives, is important and of adaptive value for regions such as the High Arctic where resources are irregular in both quantity and quality.

Eskimos on land must know intimately the behavior of game, but on sea ice they must also know the behavior of the ice itself (93). Such knowledge comes about slowly through the process described above. Eskimos, for example, know that young salt ice (i.e. in the fall) is flexible rather than brittle. When sleds begin to sink, they know that it is best to keep the sled moving and "ride out" the thin ice spots. Eskimos make use of *color* as a distinguishing feature between different types of ocean ice. In inland lagoons, however, color is deceptive because of suspended sediment. Unsafe thin ice tends to be very dark; as it thickens it becomes gray, and from this point on to darker color gradations it is safe enough to support a man and a loaded dog sled (93, p. 16). The use of color distinctions is particularly

useful since it allows an Eskimo to determine conditions ahead of time and to lead his dog appropriately. This method is said to be nearly 100% effective—although not entirely infallible.

Eskimos' avoidance of risky situations and knowledge of ice serve them well, but accidents still occur. In the past, Eskimos went on ice prepared for many types of emergencies. The ice probe (*unaak*) is a safety aid used to avoid being swept by the current underneath the ice or to spread one's weight on thin ice. If one falls through and comes out soaking wet, it is customary to *run* back to the village to keep warm. If too far from a settlement, the hunting partners may lend extra items of clothing until the soaked garments dry. The skin and fur clothing is relatively waterproof, and if powdery snow is available nearby, it can be used to blot the moisture before it soaks in and freezes (93, pp. 24–28).

In addition to his extensive knowledge of the environment, the Eskimo usually is in good physical condition, although not extremely so for an active person. Shepard (105) has reviewed work performance among Eskimo and Ainu populations. There appears to be no appreciable difference between mean values for Eskimo VO_2 Max and those for other populations. In Eskimo performance, patience, experience, and skill in interpreting small signs are more important than a superior oxygen transport system (100). There has been a steady decline in physical capacity in recent years as a result of changing life-styles. Young Eskimos are much less willing to face up to the rigors of the hunting way of life (93).

To cope with snow and ice cover, Eskimos rely on keen observation to avoid unnecessary expenditures of energy and unnecessary dangers. Foresight is particularly crucial, as shown by their unwillingness to travel onto sea ice in winter unless they have carefully excluded all potential signs that they might be set adrift on a loose floe. Nelson has noted that Eskimos seldom act in the Western manner of doing things for the excitement of taking a chance (93, p. 377). Instead, they carefully avoid percentage risks, even when the risk may be as low as 20%. Alertness is also valued, and seldom do they give their full attention to a single activity. Instead, they commonly glance around them and survey their surroundings. This avoids the danger of being carried away by floating ice, presents opportunities for hunting other animals than the one being stalked, and familiarizes each person with his surroundings. Eskimo hunters exercise unusual inventiveness in crisis situations. In one case noted by Nelson, they constructed an emergency sled from pieces of frozen meat (93, p. 378). Cooperativeness in hunting also enhances the survival chances of the individual through pooling of physical effort and environmental knowledge. The common reaction to mistakes is laughter rather than anger, and this helps alleviate the frustrations that are sure to occur frequently in an environment where so much

can go wrong. Many of these traits have begun to disappear with the steady acculturation of Eskimos to Western culture and the adoption of time-saving technologies.

ADAPTATION TO PROLONGED LIGHT AND DARKNESS

Arctic populations are subject to fluctuating light/dark cycles in the spring and fall, and to no cycling at all in midsummer and midwinter (17, 43). This unusual pattern is believed to have a negative effect upon the well-being of the population, including reactions such as arctic hysteria,[6] the physiological basis for which is discussed elsewhere (17, 43, 92, 106a).

Cases of arctic hysteria have been noted as long as outsiders have known Eskimo populations. They were said to be more frequent among women than men, but no one ever gave the matter sufficient attention to permit any assertions on the subject (43). Nachman (91) has suggested that such attacks may have served to socially express role demands. He explains that in the case of women the attacks might provide an opportunity to acknowledge sexual threats and temptations normally not permitted. Men, by the same token, might be able to express fears about their inability to fulfill the responsibilities of married life. Arctic hysteria may have been a way by which Eskimos reacted to intense stress, but Bohlen (17) cites evidence to the contrary. Such stress might be associated with the low and steadily depleting food supplies of wintertime. Wallace (114) has suggested that numerous factors are probably implicated: shamanistic outlets for hostility, hypocalcemic levels resulting from a low calcium diet and low vitamin D synthesis during winter darkness, and anxiety over subsistence.

A great deal of the stress that is implicated in arctic hysteria was relieved through religious practices. Eskimo religion was essentially animistic, where animals and other environmental aspects were imbued with supernatural will and power. Religion, therefore, sought to create a meaningful and peaceful relationship through taboos, ceremonials, and practices that prevented excess slaughter of animals, provided release from tensions, and defined human roles and actions (83). Religion helped Eskimos explain bad weather or reduced game supply (28). Personal guilt and misfortunes could be transferred to the machinations of angry spirits (118). Taboos helped regulate the time for making new clothes, for conserving energy and resources, and for establishing priorities. They might also have helped estab-

[6]Arctic hysteria, or *pibloktok,* is a temporary mental disorder characterized by alterations in consciousness, memory loss, psychomotor seizures, and other symptoms that resemble epilepsy (43). Bohlen (17, p. 73) believes it may be triggered by low calcium levels when the body requires maximum levels.

lish a circannual rhythm that could help alleviate the disturbances brought about by the light/dark arctic pattern. In this regulation of social activity the shaman played a crucial role. If the shaman could successfully forecast the weather, help cure the ill, bring good luck to hunters, and make game receptive to hunters, he could achieve a measure of respect and even wealth. But if his powers failed to improve the group's life-chances, he might be deposed or killed (118). Thus the group selected individuals who could forecast a number of crucial factors involved in survival and educate the group's members into the proper behavior required for well-being.

One means for coping socially with winter stress was to hold ceremonial feasts where food and other goods were distributed to the less fortunate in the group. The Bladder Festival was held in west central and southwest Alaska. It involved rituals whereby the bladders of the animals caught in the past year would return to the animals and thereby enhance future hunting chances. Shamanistic seances, the mimicking of hunting dramas, and purifications were also part of the ceremonies. The poor and the elderly were accorded special treatment and received a substantial portion of the food and goods distributed (73). Ceremonies that provided relief from sexual tension were also common. The Inglalik Feast for the Dead and the West Alaskan Asking Feast included exchange of favors and sex and ritual exchanges of male/female roles and dress (73). While their purpose was to stimulate animal reproduction and enhance hunters' chances in the next season, they probably helped relieve social and psychological tensions as well (83). The Messenger Feast was a high point of winter, and served to facilitate social and economic exchange (107, pp. 217–28), manifesting numerous similarities to the potlatches of the Northwest Coast.

Western regimentation and diet have facilitated Eskimo adaptation to the light/dark arctic pattern. Eskimos have acquired watches, schools have introduced a scheduling element that strongly socializes the child into the 24-hour rhythm, and the introduction of milk products into the diet has enhanced the calcium levels of Eskimos and facilitated calcium homeostasis. The adoption of wage labor requires being at work at stated times, often according to a schedule more familiar in New York than in the Arctic. These socially prescribed schedules facilitate the physiological performance of Eskimos—although not all the changes have been for the better. Concentration in villages has led to abandonment of traditional housing and adoption of less healthy shelters. Instead of the sod and snow igloos, Eskimos now live in plywood shacks or government-built prefabricated homes heated by coal stoves where air is not properly humidified and the population is all the more susceptible to respiratory infections. This adds to the chronic problem of middle ear disease (*otitis media*) and deafness among Eskimos. Such impairment surely affects the emotional profile of Eskimos

and facilitates their susceptibility to nervous disorders similar to arctic hysteria, and it may be implicated in problems of foreign language learning and school performance (43).

COPING WITH LOW BIOLOGICAL PRODUCTIVITY

The low net productivity of the tundra imposed on the human population of that zone a constraint that they could overcome either by seasonal exploitation of more southerly taiga resources or by exploitation of the coastal resources. Both strategies have been used by distinct groups of Eskimos, but interdependence between the groups was created through need to trade the resources of one group for the other (107, p. 76). The coastal Eskimos lived in small but relatively permanent settlements oriented to the seasonal but regular appearance of large numbers of sea mammals —used not only for food but also for clothing and fuel. Inland Eskimos, on the other hand, were more nomadic and followed the herds of caribou and exploited the fish of the rivers and, in their excursions to the coast, sea mammals. The inland population depended on the coast for supplies of seal oil and other fuels while the coast depended on the interior for caribou skins and plant products, particularly vitamin-rich berries (94). Not much has been made of the Eskimo use of plant foods, but it is known that when berries were available, they were stored in seal oil or in the permafrost (94).

The maintenance of interdependencies among Eskimos was facilitated by flexible alliance systems. Although there was rarely intermarriage across the inland/coastal boundary, an elaborate quasi-kin system evolved that allowed the extension of hospitality and protection and encouraged trade (107, p. 95). Eskimo kinship has been said to be flexible and to permit inclusion of strangers into the network whenever appropriate (22). The flexibility of Eskimo settlements is a response to scattered resources and aims at an increasingly secure subsistence.

Balikci (6) discussed the order and predictability of the Netsilik Eskimo annual round. Table 1 summarizes the resources exploited and the type of groups and cooperativeness associated with each activity (5, p. 10). The single extended family unit was maintained year-round, but other affinal and consanguineal ties led to aggregation when such groupings maximized hunting chances and provided greater security at uncertain periods (i.e. winter).

Winter sealing facilitated the formation of relatively large winter villages made up of several extended families, while summer fishing was a time for efforts by small families. Seal-meat sharing patterns reflected precise rules of cooperation:

Table 1 Reconstruction of the annual migration cycle of a Netsilik subgroup (ca 1919)[a]

Camp no.	Season	Subsistence activity	Cooperation	Housing
1, 2	Midwinter	Seal hunting at breathing holes	Large hunting parties, intense social life, ceremonial activity	Sod, stone, and snow villages
3	Spring	Seal hunting at large breathing holes	Scattered, extended family units	Snow igloos
4	Midsummer	Fishing at stone weirs	Restricted, extended families	Seal tents
5	Early fall	Caribou hunting inland	Cooperation, kyak hunting. Close cooperation between beaters and spearers	Seal tents
6	Late fall	Fishing through thin river ice	Cooperative fishing with leisters	Seal tents

[a] Based on (5, 6).

> The seal-meat sharing system functioned as follows: every hunter had a number of sharing partners for each part of the seal meat and blubber . . . Ideally, there were twelve and they were chosen by the hunter's mother either shortly after birth or during his childhood. Whenever the hunter killed a seal his wife cut up the animal and gave the appropriate parts to each one of his partners' wives (5, p. 125).

Partners named each other by the name of the part of the seal exchanged, and this reinforced the sense of cooperation required during the long dark winter months. What is of great ecological and social interest is that close relatives and members of the same commensal unit could not become partners. Only distant kin or nonkin were eligible, thereby extending the network of subsistence and overcoming the hostility that was often directed at those outside the extended family in Eskimo behavior (5).

Exploitation of the scarce and sometimes fluctuating resources necessitated the practice of population controls to adjust the size of families to the capacity of the provider and enhance the survival of the living and productive members of the group (1; 6, p. 81). The most common practice of population control was female infanticide.[7] Eskimos gave cultural preference to boys and considered girls to be less productive than boys, the hunters. Thus, normally families tried to maximize their number of boys,

[7] Although Spencer (107) notes that coastal Eskimos practiced sexual abstinence in late winter to assure success in the hunting of whales, Freeman (44) proposes cultural and ecological factors for Netsilik Eskimo infanticide. Schrire & Steiger (103) imply that infanticide serves group level adaptation, but question whether more than 8% of female infants could be killed without endangering the population's survival.

although in times of stress male infants were killed as well (5). Female infanticide may have taken into account the higher death rate of males who, while hunting, froze to death or were killed in disputes. Suicide, senilicide, and invalidicide also served as means by which there was cultural pressure to eliminate unproductive members of society—a task that the nonproductive individuals often allocated to themselves through voluntary abandonment (107, p. 82). One should not assume that female infanticide and other population controls were evenly practiced throughout the Arctic. As one moves to areas where winter ice prevents access to intertidal areas, the old, the infirm, and the young become potential candidates for abandonment and exposure to the elements (34). One does not find these practices as often in areas where these three subgroups can obtain a sizable portion of their own food supply, in particular shellfish (77, p. 242). When such intertidal areas or coastal resources are not available, a feedback process may go into effect by which the population adjusts to the leanest months of the year and to the areas with the least resources. Prolonged nursing, abortion, sexual abstention, as well as infanticide, may all be utilized to limit the numbers of people.[8]

Implicated in the practice of senilicide may be a pathological condition in aging Eskimos known as bone resorption. While the causal factors are not well established (85, 121), the condition is known to lead to increased frequency of vertebral fractures. Such increased impairment which would cripple the aged person would have put a major drain on seminomadic communities. By way of contrast, coastal populations could store food for lean times, and such sedentariness permitted the old and infirm to continue contributing to group subsistence instead of becoming burdens (107, pp. 92–95). Laughlin has pointed out that the richness of the Aleut intertidal ecosystem permitted greater longevity and that older Aleuts played an important role as "consultants and cultural librarians" (78). Table 2 illustrates the greater number of persons to survive to ripe old age in the Aleutian Islands compared to Labrador Eskimo populations. While these are not appropriate High Arctic samples, they do suggest the need for further research on arctic demography.

Three social features have been noted in the Arctic that enhance the adjustment of the human population to the more marginal areas of the Central Arctic: institutionalized adoption, child betrothal, and spouse exchange (33). Through adoption the population can be redistributed accord-

[8]In humans, prolonged lactation only incompletely suppresses ovulation. Birdsell has suggested that the demands of nursing a previous child and of mobility may have made it necessary to kill 15 to 50% of the children born (12, p. 243). Schrire & Steiger (103) estimate a maximum figure of 8%.

Table 2 Age at death in populations of Aleuts[a] and Eskimos[b]

Age groups	Number	Aleut percent	Number	Eskimo percent
1–15	150	30.55	38	34.55
15–25	41	8.35	10	9.09
25–45	103	20.98	29	26.36
45–65	117	23.83	20	18.18
65–80	58	11.81	13	11.81
80–100	22	4.48	0	0.00

[a] Aleuts of the Aleutian Islands (78, p. 386).
[b] Eskimos of Labrador (78, p. 386).

ing to sex as well as into viable units for specific areas. The value of child betrothal is tied to the practice of female infanticide. A male could assure himself of a spouse by arranging to marry a female infant. This might also free him to give full attention to hunting rather than spending time in search of eligible females. Spouse exchange is sometimes cited as a means to extend one's kinship network through the mechanisms of exchange and cooperation (107). Damas (33) suggests that it may also alleviate the tensions of monogamous sexual life. All three features helped regulate the size of groups and their reproduction and affirmed their cooperation in the search for scarce resources.

Despite the absence of plants in their barren tundra surroundings, the High Arctic Eskimos practicing a traditional subsistence pattern had a nutritionally adequate diet. The major portion of the native diet consisted of seal, walrus, whale, caribou, and fish—a diet high in protein and fat but very low in carbohydrates (35, 36, 94). This native diet, when prepared in a traditional manner, was capable of furnishing all essential nutrients (35, 36). For useful reviews of nutritional research among arctic populations, see 8, 9, 35, 36, 106a.

The well-being associated with this native diet—low blood pressure, low blood cholesterol, and lean body mass—has changed in the last 20 years. Today the health status of the Eskimo more closely resembles that of Western industrial populations. A greater proportion of the calories consumed are now derived from carbohydrates—especially breads, cereals, rice, and sugar. Over one-half of the fat currently used is imported, primarily in the form of hydrogenated shortenings and margarine. Vitamin C is in greater scarcity than before as a result of changes in cooking patterns. Anemia is now a frequent nutritional problem. Obesity, especially among females, is found with greater frequency. Hypercholesterolemia is increasing among all, particularly in the aged (9, 115, 121). Increased opportunity to obtain sweets and less frequent use of the teeth as tools have led to a rapid increase in periodontal diseases and dental caries. On the other hand, the

new diet is possibly implicated in the accelerated growth trends noted by Jamison (65)—a pattern that reflects an increased alienation of Eskimos from the limits of their environment and increased dependence on subsidies from outside.

Kemp (68, 69) has studied the flow of energy among contemporary Eskimos. Although he limited his energy measurements to two households, the model he came up with sheds light upon systemic relationships and Eskimo success in coping with low biological productivity. Modernization has led to considerable energy subsidies from outside in the form of store-bought food, gasoline, wages, and cash from art objects sold. These subsidies permit the maintenance of a larger population than before. Sedentarization is encouraged, a decreasing amount of time is spent in hunting, and ever-increasing amounts of energy are processed, with much of it lost as heat. Hunting with motorized vehicles is reasonably efficient. Kemp found that for an expenditure of 1.75 million kilocalories, the Eskimos studied obtained 5.29 million kcal—a 3:1 energy efficiency. But it means that the distance traveled is increased. Most of the calories today come from wage labor, the carving of sculptures, and skin-preparation—activities which give an even better return per unit of energy invested. The impact of the Trans-Alaska pipeline had not yet begun to be felt, but it surely means an increased flow of energy in and out of the system, although much of it probably bypasses Eskimo participation (23).

CHANGE IN THE ARCTIC

Ever since the first Eskimos came in contact with whaling ships in the 1870s, their culture has been changing, but it is only in the last 20 years that hunting has declined as a way of life while whaling has increased. Since then, a steady erosion of Eskimo adaptive practices has taken place (10). The acquisition of rifles has meant that subsistence could be secured at a faster rate than before, and the desire for Western goods demands that they work for wages so as to buy them. Despite the boom conditions in Alaska, most jobs have gone to skilled outsiders. The result has been an annual unemployment rate, adjusted for seasonal factors, of close to 70% (23). Several factors are at work, but most significant are Western education and technology. Instead of the experiential ecological education of yesteryear, modern Eskimos attend schools where education is geared toward gaining literacy by reading the wisdom of non-Eskimos. Specially influential are boarding schools that separate children from parents at a crucial time in their education as hunters. To a large extent, the influx of outsiders to the Arctic and the presence of non-native teachers have caused children to lose

respect for their traditional social and cultural values and practices. They have also learned the Western ways to become successful, and an appreciation of technological innovations, instead of guarded disapproval for change. Today, ritual regulation of human acts toward nature have almost disappeared (60).

The Eskimos, like the Laplanders, adopted the snowmobile with astounding rapidity (106). The snowmobile was developed in 1962, and since that time sales in North America have grown 2500%, and 50 manufacturers market 400 different models to supply this persistent demand (62, p. 908). Osburn (95) studied the adoption of snowmobiles among the *nunamiut* Eskimos of Anaktuvuk Pass, Alaska. Before the 1960s the population had been seminomadic caribou hunters. In 1964, the first snowmobile appeared and brought about intense jealousies among the group. For caribou hunters it was advantageous because the caribou appeared to be less afraid of its noise than of the dog teams. By 1969 the switch from dog sledding to snowmobiles was complete. Bliss (14) estimates the annual cost of a dog team at $12, while a snowmobile costs $1,075 in depreciation and operating costs. But Eskimos spent considerable effort in hunting meat to feed their dogs. In switching, all the hunted meat became available for consumption or sale. Dogs were neglected and slowly disappeared. Eskimos stopped walking and drove everywhere in their machines, even if it was only one block away in the village. Such overuse eventually took its toll, and the machines began to fall into disrepair. Lacking the capital to replace them and the know-how to fix them, the people were increasingly dependent on outside handouts and wages. But the hunting style was abandoned, and what remained bore little resemblance to the Eskimos of the past.

The change was just as rapid among the Finnish Lapps (80, 90, 97). As with dogs, reindeer sledding was abandoned within a couple of years, and the snowmobile became universal. The major difference was that the Lapps continued to herd reindeer and, in their minds, more effectively so with the snowmobiles. Before the arrival of the snowmobile, Lapps had year-round contact with herds and could easily make herd management decisions. But with the adoption of the snowmobile, pressure has been built to hold several roundups yearly instead of only one. This is in response to market demand for their product and because of the demands to meet payments on their acquired snowmobile equipment. Linkola (80) estimated that one-third of the reindeer sold yearly are required to purchase and maintain existing snowmobiles. The result has been a steady depletion in the size of the herds (see Table 3). The snowmobile has enhanced differences between people in the Arctic, with the small herder and operator having to abandon his occupation to become a full-time wage earner to sustain his family and new

Table 3 Patterns of reindeer sales and herd growth in a Lapp community before and after the use of snowmobiles[a]

Period	Reindeer slaughtered and sold	Net increase in herds
1956–1961		
By owner A	25.5%	1.7%
By owner B	15.5%	34.4%
By owner C	22.7%	13.5%
By all 104 members	23.7%	7.8%
1963–1969		
By owner A	43.7%	-16.8%
By owner B	32.6%	-17.4%
By owner C	43.0%	-20.2%
By all 111 members	32.7%	-10.0%

[a]Owners A, B, and C have the largest herds in Utsjoki (63).

machinery. In addition, the snowmobile scars the Arctic. Ecologists have noted that plant recovery is slow where snowmobile tracks have been cut as far back as 10 years ago (14).

An important issue in recent years has been discussion of the application of techniques to ameliorate arctic climate. There is no doubt that it is climate which most inhibits the development of the Arctic. The outlook at present is not particularly encouraging. Efforts to produce rain have given poor results. A Bering Straits dam has been mentioned as an effort to warm the Arctic, but engineers lack sufficient knowledge to undertake such a project, and it could have deleterious effects elsewhere. At this time it appears that regional climatic modification is untenable (82, p. 338). Local microclimate modifications may be possible, however. Whether such efforts would be desirable or economical is another question. Snowmelt may be accelerated by appropriate artificial dusting or inhibited by artificial insulation. Snow fences, i.e. the use of trees as snowbreaks, can increase or decrease snow cover depending on location. Powdered coal, sprinkled over the ground, may increase soil temperature by tapping solar energy (82).

It is most unlikely that outdoor agriculture will be of much consequence in the tundra-covered areas—barring some unforeseen and spectacular breakthrough in technology (25). Even when good arable soils are available, the climate is unsuitable for most crops domesticated heretofore. As facilities improve, transportation systems can bring produce from favorable areas, and this is likely to further inhibit the economic basis for developing agriculture in arctic zones. The development of the Arctic in the foreseeable future will follow an extractive path, and it can only be hoped that the effect

will be different from what it was in the Amazon Basin rubber boom of the late nineteenth century, which ended with the region still undeveloped (87a).

CONCLUSIONS

An evaluation of the impact of the proposed Trans-Alaska pipeline conducted by the Bureau of Indian Affairs concluded that, although the pipeline did not cut across a sizeable number of Eskimo villages, it would increase the pace of acculturation and absorption of Eskimos into Western culture (23). The impact of change in its initial stages is seldom kind, and thus far its impact on Eskimos from a cultural and ecological point of view can only be said to have been unfavorable. The health status of Eskimos has declined—anemia, obesity, higher blood pressure, hypercholesterolemia, loss of teeth—without a marked improvement in the persistent problems of otitis media, gastroenteritis, respiratory ailments,[9] and eye damage (115, 121). In schools, Eskimos are slow to learn because of a combination of chronic hearing impairments, passive teaching techniques, and a lack of respect by non-native teachers for their Eskimo pupils (29). Technological improvements such as snowmobiles have been adopted before adequate knowledge of engine repair and vehicle maintenance were provided. The result has been neglect of traditional transportation means and increased dependence on wages to keep up an expensive technology that most Eskimos cannot afford because of unemployment.

According to Smith (106), Eskimos can still live off the land by hunting on weekends and keeping a job during weekdays. But new problems arise. Because the snowmobile permits more distant trips, there is greater danger of being stranded too far to be able to get back on foot. The speed of snowmobiles increases the danger of frostbite from the combined effect of cold and wind from the speeding vehicle. The driver of the snowmobile cannot see if anyone traveling on the sled behind him has fallen, and cases have been noted of companions being frozen to death after falling from sleds.

Eskimo interpersonal relations have changed a great deal, but recent events have brought on a renewal of Eskimo traditions. Following a lengthy transitional period (1850s to 1960s) in which Eskimo kinship networks broke down as families settled among strangers in villages, it is amazing that any aboriginal customs have survived (21). Modern advances in communications equipment available to the mass consumer have facilitated a return to activation of wide kin networks. Most Eskimos in Northwest Alaska

[9]Except for a sharp decline in the incidence of tuberculosis.

have tape recorders and use them to make recordings for relatives in distant villages. Relatives who have never even met are included in these tape networks which integrate the Eskimo population. Another crucial change is the construction of landing strips in most villages and the use of charter flights to attend, en masse, cultural events in other villages. While Eskimo economic behavior is increasingly Western, a great deal of the kinship obligations are still operational and appear to be on their way to a revival. For a full discussion of these changes, as seen among the Northwest Alaska Eskimos, consult Burch (21).

A recent Inuit Circumpolar Conference[10] gives evidence of efforts by Eskimos to act jointly to preserve their cultural heritage, gain a voice in how their environment is exploited, and agree on conservation measures that allow them to sustain a hunting way of life in the modern world (88). Despite initial difficulties in communication, the Inuit responded in unified resolutions. Whether this growing unity is translated into a growing control over their destiny remains to be seen. But the goal of a renewed Inuit life-style more closely attuned to the opportunities and limitations of the arctic environment is a hopeful one. The influence of outsiders has thus far meant a replacement of adaptive behavior by technological subsidy. Such a subsidy is expectable only as long as the area continues to yield high-value nonrenewable resources. Once they have been extracted, the Arctic will need once again the ancient strategies of Eskimo populations. We can only hope that the adaptive value of such a life-style is recognized and nurtured by both Eskimos and outsiders.[11]

The bulk of the mechanisms for human adaptation to arctic areas are social and cultural rather than acclimatory, developmental, or genetic (101). Housing and shelter provide effective regulatory adjustments to cold stress and create microenvironments of relative comfort. These are supplemented by acclimatory and developmental adjustments that protect the extremities: nonshivering thermogenesis, high rate of peripheral blood to the extremities, and high core-to-shell conductance. A remarkable adjustment, whose origin is not fully understood, is the calorically expensive but effective higher basal metabolic rate of the Eskimo. Adjustments to a snow environment, to prolonged periods of either light or darkness, and to the low biological productivity of the Arctic are regulatory in nature. Traditional education emphasized observational expertise, knowledge of animal

[10]The term Inuit is rapidly replacing the term Eskimo. In this review the older term is used because it is more familiar to the non-Arctic specialist.

[11]Bruemmer (18) has produced a beautiful and sensitive photographic essay that effectively captures the adaptability of the Eskimos to the Arctic.

ethology, and careful avoidance of risk. In combination, these adjustments were conservative measures for preventing accidents in an environment where death can come quickly in either freezing water or cold snow. Adjustments to prolonged light and darkness cycles were social and cultural in nature. The traditional animistic religion helped reduce anxiety over resources, signaled the time for social aggregation during the peak of winter, and through rituals and feasting created an artificial 24-hour daily rhythm that may have helped prevent disruption of physiological functions and reduce the frequency of arctic hysteria-like incidents. The low biological productivity of the tundra was dealt with by the exploitation of animals whose diet is not based on tundra plants: sea mammals, fish, and land animals that exploit during winter the forest resources to the south. Marriage practices, adoption, spouse exchange, and meat-sharing partnerships all helped extend the network of friendship and reciprocity, thereby improving the life chances of individuals and nuclear families scattered over the vast arctic zone. Population controls helped maintain a balance between resources and population.

While the discussion in this review has emphasized the identification of crucial constraints to human adaptation and discussion of the adjustments that facilitate human adaptability to such constraints, it should not be forgotten that these constraints occur simultaneously and influence the type of adjustment that results. For example, both high altitude populations and arctic populations are exposed to cold stress (27, 49, 98). They both share nonshivering thermogenesis and peripheral blood flow to the extremities. High core-to-shell conductance and higher basal metabolic rate, however, are found only among arctic populations. To understand this difference in human adaptation to cold we must look at the other constraints under which high altitude and arctic populations operate. While arctic populations exploiting coastal sea mammal resources were rarely exposed to hypocaloric stress, high altitude populations seem to have been regularly exposed to it. This means that adaptations to cold at high altitude had to be energy-saving rather than energy-costly, while in the richer marine areas of the arctic environment, caloric considerations were relatively unimportant. Similar interacting effects are possible for a number of other problems discussed in this review, but they have not been researched adequately to date.

Research on arctic zones needs to continue because of the importance of understanding how social and cultural adjustments function jointly with physiological responses to stressful conditions. Current economic conditions in the Arctic provide an unusually interesting natural laboratory—given the presence of both native peoples and large numbers of recent migrants. Because most of the adjustments are social and cultural, the

problem is not the danger of losing important genetic adaptations, but rather of losing the delicate knowledge of arctic natives about their environment and of submerging an environmentally fine-tuned people under the weight of imported technological advances whose impact upon the arctic ecosystem is not understood.

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