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ARE ARCTIC ECOSYSTEMS VULNERABLE?

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Introduction.

Geographers and international legislators frequently define the polar circle, at $66^{0}33'$, as the border of the Arctic regions. This delineation can be satisfactory enough in legislation and administration, but it is not a good biological definition. Biologists prefer to use a definition which is based upon climatological and biological characteristics. The 10^{0}C isotherm, i.e. north of which average summer temperatures in the warmest summer month does not exceed 10^{0}C, is a good and commonly used definition for the borders of the Arctic. It is a good correlation between the 10^{0}C isotherm and the border of the tree-line, north of which trees cannot grow. Biologists commonly use the 10^{0}C isotherm or the tree-line as borders when they delineate the Arctic (Fig 1).

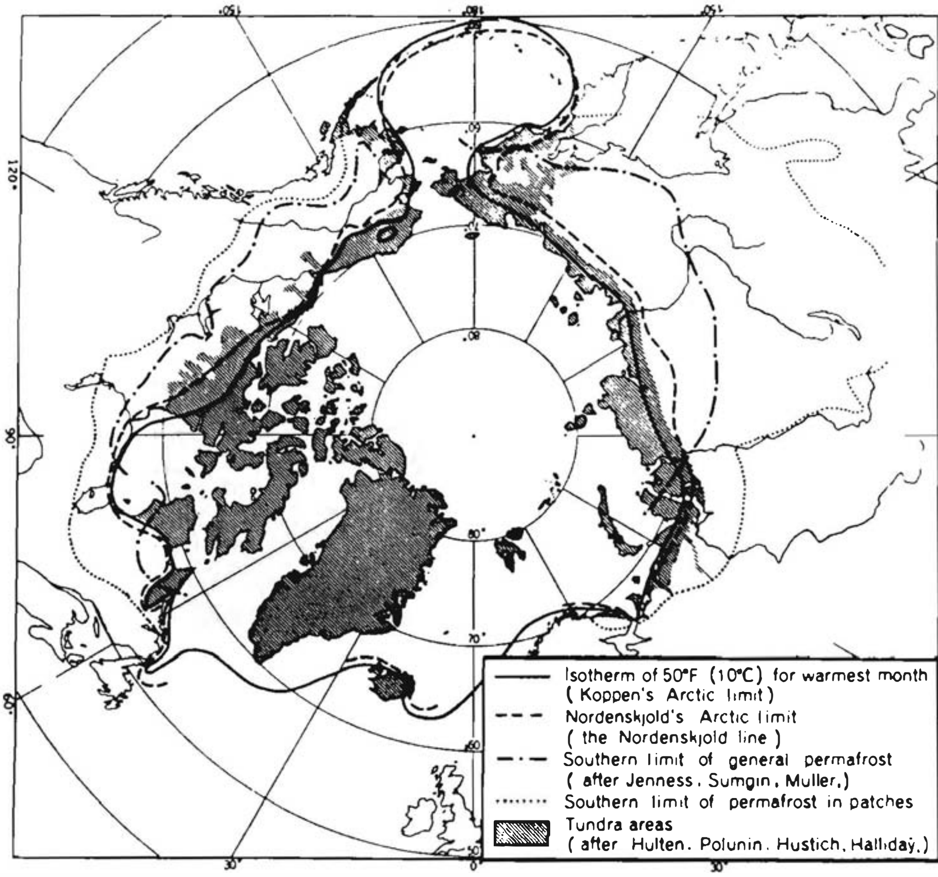

Fig. 1. Delineations of the Arctic. ———: The 10^{0}C isotherm for warmest month. —·—·—: The southern limit of the general permafrost, or tree-line. From Irving (1972).

The central part of the Arctic, as defined above, is a large and deep ocean, which is ice covered most of the year. The sea ice is constantly moving with changing currents and winds, breaking the ice up in floes, with leads that open and close and pressure ridges criss-crossing the sea ice in all directions. The polar basin is surrounded by islands and land masses. Many arctic land areas are permanently covered by ice, of which the Greenland ice cap is the largest. However, inland ice in the Arctic are never as thick and massive as e.g. in Antarctica.

Arctic ecosystem characteristics.

A visitor who goes north in the Arctic summer is often struck by the surprising abundance of plants, birds and mammals. But he will also notice that plants and animals live under extreme and sometimes marginal conditions, that species are few compared to other areas, and that animal populations often fluctuate dramatically. He observes that most birds must leave for more favourable conditions on other latitudes when the summer is over. The species which remain struggle to survive during a long Arctic winter night, when food is scarce, and when very low temperatures, bad weather and snowstorms prevail.

Anyone who travels in the Arctic, and who visits areas where human activities have been going on for some time, is struck and often shocked by the impact caused by industrial activities and transport. Tracks of vehicles which have passed the tundra are often visible years afterwards. Erosion has often enlarged the tracks and turned them into deep trenches or small creeks. It is therefore understandable that our visitors immediate conclusion is that the life conditions are marginal, and that the ecosystems are less capable of coping with damages of various sort. Consequently, the species which belong to arctic ecosystems must also be particularly fragile and vulnerable.

Such impressions are often reflected in statements in official policy documents, as NOU 1973: 19: Nature conservation in Svalbard. Here we can read the following: "The Arctic represents a marginal area for all life on Earth. Low temperatures and short growth seasons result in slow biological, biochemical and chemical processes, and ecosystems have consequently less ability to recover from damages and disturbances than they have on lower latitudes...... Life systems are particularly vulnerable because they are highly specialized. (Anon. 1973). In St. meld. 26, 1982-83 (1.2), we read: Ecosystems in polar regions are particularly vulnerable......Because there are only few plant and animal species, damages in one link of the system can affect others. (Anon. 1982)

Comparisons between ecosystems: arctic versus the tropics.

Ecosystems in tropical areas have commonly been regarded as particularly stable, because of the richness in species which live under favourable environmental conditions. In my discussion about arctic ecosystem vulnerability and fragility, I have therefore chosen some examples from tropical ecosystems, and particularly from the rain forest, which I compare with arctic ecosystems. I choose terrestrial ecosystems, because climatic and nutritional fluctuations are more pronounced on land than they are in limnic and marine environments.

Definition of vulnerable

However, before we go any further in comparing ecosystems and before we start to discuss differences, we need to define what we really mean by the term vulnerable. It is not a strict ecological and biological term. IUCN classifies a species to be vulnerable if it "--- is likely to move into the endangered category in the near future if the causal factors continue operating". The term endangered is defined as "taxa whose survival is unlikely if the causal factors continue operating".

Vulnerable is therefore a relative and not quantified term. It is linked to negative causal factors, which are not further defined, but which can be natural or man-made. The IUCN definitions link vulnerability to an undefined ecosystem instability where negative factors have a continued and detrimental impact upon species and populations. Vulnerability can perhaps be illustrated by some examples: Passenger pigeons in North America and great auks in Europe became extinct because they were particularly vulnerable to hunting. Passenger pigeons congregated in huge flocks in trees where they easily could be shot in great numbers. The flightless great auks also congregated in flocks where they could be killed by primitive means. Some falcons and other birds of prey are vulnerable to pesticides because such chemicals cause thin eggshells and prevent reproduction. Acid rain is harmful to lake trouts. Cochroaches, house sparrows and Norwegian brown rats are not vulnerable, because they seem to be able to survive under any conditions offered.

Definition of stable

Scientists have sometimes put a sign of equation between vulnerability and stability, and have stated that the instability of ecosystems is a proof of their vulnerability. I find it therefore necessary to define what we mean with the term stable. Pimm (1984) defined an ecosystem as stable "---if and only if all its variables are able to return to an initial equilibrium following it being perturbed from it." A perturbation from equilibrium is furthermore characterized by the degree of resilience, i.e. how fast the variables perturbed return to equilibrium, and resistance, i.e. the degree to which a variable is changed, following a perturbation. Let us use a very simple example : A pencil which is put on its end on a table can be stable in this upright position. But it is unable to return to this position if tipped over. The pencil is most certainly vulnerable to a disturbance or perturbation, even if it seems very stable in its intial position. Most of us have as children played with the plastic or wooden toy, which had a solid piece of lead in its bottom. If pushed, our toy would tilt back and forth for some time. But sooner or later, it would stop in the position it had before we started to push it. It cannot be very vulnerable to what we regard as a disturbance, because it is able to regain its initial position after perturbations.

Species diversity

One argument which is commonly used to justify the statement about the vulnerable and fragile Arctic - as in the official documents above - is that only few species are able to live and reproduce in polar regions, on the verge of where life can exist at all. If we travel to the high arctic Baffin Land in Canada, we find only 200 flowering plant species. In temperate regions in America, e.g. in Massachusetts, the number has increased to 1650. In Florida, where the climate is subtropical, the number of flowering plant species is 2500. We find a similar pattern if we choose to study animals. There are 90 species of beetles on Baffin Land, 2000 species in Massachusetts, and more than 4000 in Florida. In Svalbard, there are about 170 vascular plant species while the number in mainland Norway is close to 1800 species. Only 25 bird species are regular breeders in Svalbard, compared to 230 species in mainland Norway. There are only two species of mammals which occur naturally on land in Svalbard, namely the arctic fox and the reindeer. The land living mammalian fauna on the Norwegian mainland counts 46 species. We find a comparable decrease in species diversity in marine ecosystems, if we travel from tropical and temperate regions, towards the Arctic.

When we compare species diversity throughout the Arctic, we end up with a general rule of the thumb: the abundance of plant and animal species increase as we travel from the high Arctic towards temperate regions, and to tropical areas (Fig. 2).

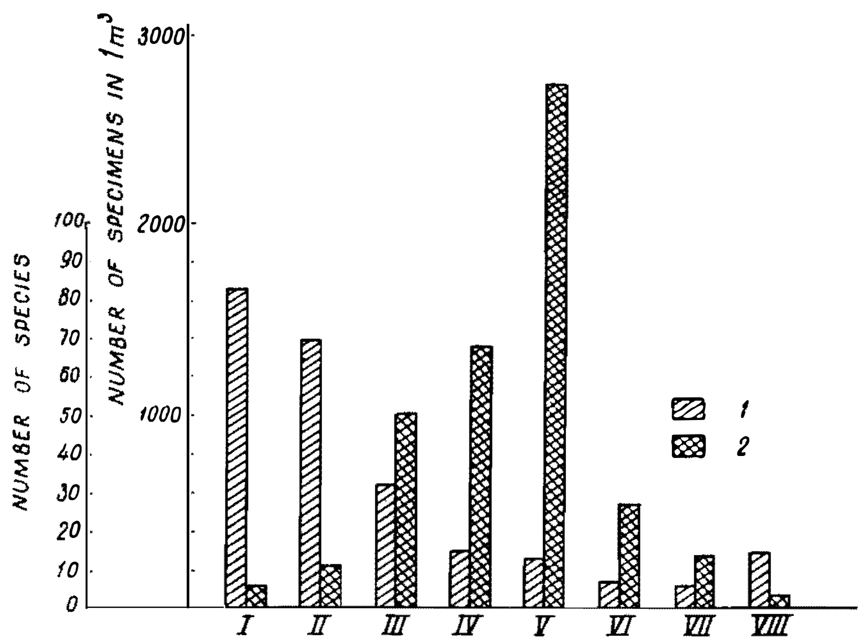

Fig. 2. Changes in the number of species (1) and in the number of specimens (2) per m^2 of the Pacific Ocean, from tropical (I), northern (II, III), Bering Sea (IV, V), Chukotsk Sea (VI, VII), to the Polar Basin (VIII). From Remmert (1980).

Diversity versus connectance.

The British ecologist Charles Elton (1927) stated that arctic ecosystems were particularly susceptible to disturbances, because of their low species diversity. He and other scientists compared arctic ecosystems with agricultural monoculture systems, where pest outbreaks can be common and often detrimental. According to them, the low diversity of arctic ecosystems was in itself a proof of ecosystem instability. A common view was that the accumulation of biological diversity in an ecosystem was a necessity to promote stability. Prior to 1970, most scientists agreed that high species diversity was an ecological advantage. Ecosystems with high diversitiy, e.g. the tropical rain forests, were considered to be particularly stable and therefore less fragile or vulnerable.

However, diversity cannot be regarded isolated. The importance of species diversity in any ecosystem is strongly dependent upon how species interact. MacArthur (1955) stated that the more pathways there were for energy to flow in an ecosystem, the less severe would the system suffer from a failure to any one pathway, and the more stable would the ecosystem be. Or in other words: if species were less specialized, and less dependent upon each other, e.g. if they were able to switch from one reproductive strategy to another, or from one food source to another, then the ecosystem as a whole would be more able to cope with changing ecological and environmental conditions. The common ecological philosophy and thinking was another version of the old and common safeguard rule: "Dont put all your eggs in one basket".

The relationship between connectance and diversity was demonstrated in computer simulations by Gardner and Ashby (1970). They found that if only ten species in a system interact at a 13% level, then only small changes (2%) in connectance affect the stability dramatically, from almost certainly stable to almost certainly unstable. If the number of connected species is less, e.g four, then stability was found to have an almost 40% probability when connectance was 100% (Fig. 3). May (1972) found that twelve species communities which were modelled with

15% connectance had a probability essentially equal to zero to be stable. If, on the other hand, the same community was arranged in three independent blocks of four species each, and each block had 45% connectance, then the twelve-species model would be stable with 35% probability.

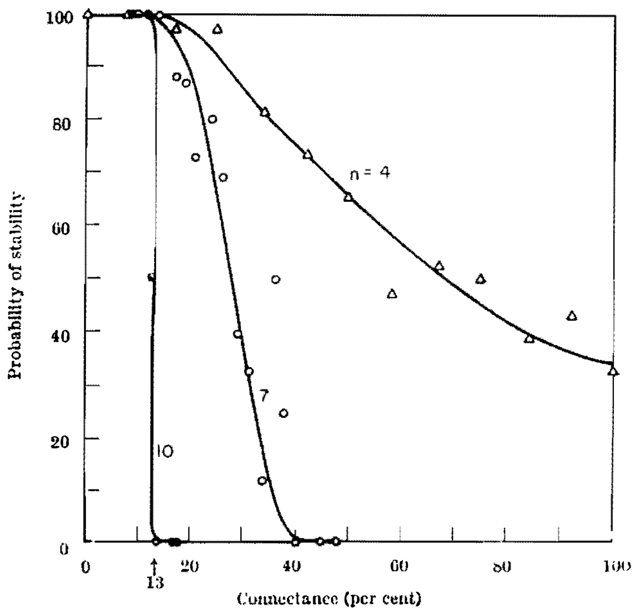

Fig. 3. Variability of stability with number of species and the connectance between species. From Gardner and Ashby (1970).

The common conclusions of recent ecological research and computer modelling is therefore that ecosystem stability is very dependent upon the combination of species diversity and connectance between species. In their discussions of stability versus species connections, Wiman and Holst (1982) and Pimm (1984) concluded that the more species that are present in a community, the less connected it should be and the less resilient would be its populations. The more connected a community, the fewer species it should have if it is to be stable. Strongly connected communities are more likely to lose species if one is removed. Consequently, the more resilient will be its populations.

Population fluctuations in arctic ecosystems.

One common line of evidence in earlier ecological research for Arctic ecosystem instability was the prevalence of large population fluctuations in polar regions. A common statement was that such fluctuations were less pronounced in temperate and tropical areas. It is true that animal populations which live in the Arctic often show wide population fluctuations. Examples are many. Vibe (1967) demonstrated such population cycles in many species in Greenland. He explained the observed changes in number of individuals in many populations to be caused mainly by climatic factors, and snow and sea ice cover. Violent fluctuations in the number of lemmings and other small rodents are known from many arctic areas. Combined predator/prey fluctuations are also well known, as in arctic hares and lynx from Canada, and in lemmings and snowy owls in the North American and European Arctic (Remmert 1980).

However, many of the arctic population fluctuations mentioned above are cyclic by nature, i.e. populations will return to an equlibrium stage or cycle around an equilibrium stage after perturbation. Consequently, such fluctuations need not be detrimental to the species or populations concerned. It will be the degree of resilience and resistance which determine how vulnerable the populations are after they have been perturbed. New ecological or man-made factors can affect resilience and resistance, and prohibit population recovery. Such events can be particularly harmful if they are introduced when populations are at a low level.

Population fluctuations in tropical areas

Population fluctuations are not exclusively linked to arctic or other marginal ecosystems. Their importance as they are determined by resilience and resistance, can affect populations of plants and animals in any part of the world, if they occur. Early studies stated that population fluctuations rarely occurred in tropical ecosystems, because of their species diversity and consequent stability. This statement was based on fragmentary and often anecdotal information. More recent studies have given a different picture. Wolda (1978) showed that insect populations in tropical Panama fluctuated as much as their counterparts from wet temperate zones. Physical stability and environmental predicatbility were important for determining annual population variations, and factors as low and unpredictable rainfalls had a particular important impact in the tropical areas studied. Wolda rejected the hypothesis that stabilities were higher in tropical insect populations.

Goodman (1975) lists a number of examples of population fluctuations from tropical areas, such as defoliating of Brazil-nut trees in Bolivia by exploding insect populations, monkeys succumbing in large numbers to epidemic diseases, and lungworm plagues which have caused periodic decimation of zebra populations. A rinderpest epidemic that affected all of Africa in 1890 was so severe that one of the most common game animals, the Cape buffalo, became locally extinct in many areas. Goodman also lists examples of periodic fluctuations in tropical plant and animal populations. Synchrony in seed sets in tropical bamboo species causes violent population fluctuations in rodents which are feeding upon such seeds. Population fluctuations of Indian elephants have ben observed to take place with about 70 years intervals. Goodman states that "---suspicion of the conventional wisdom that tropical biota are stable would be well placed."

Different strategies in tropical and arctic ecosystems.

The niches occupied by tropical plant and animal species are often very narrow, and the species themselves are highly specialized. Tropical species are often very selective with regard to nutrients and food, and often specialized with regard to their reproductive strategies. Many tropical plants have a symbiotic relationship to other plants or animals. Tropical rain forests can, however, normally afford high species diversity and high connectance between species because the environmental conditions are relatively stable.

The arctic ecosystems, on the other hand, meet the stability requirements in a harsh environment with other strategies. Climatic fluctuations and changes in nutrient and food supply can be dramatic. Consequently, low diversity and low connectance are important if stability is to be obtained. Arctic plants can have a vegetative propagation when climatic conditions are bad, but reproduce sexually under more favorable conditions. The percentage of species which do not form seeds, but which propagate in various asexual ways are doubled in the Arctic compared to temperate regions (Beschel 1969). Many plant species are adnate, and can dry out if precipitation is low. They constitute about 60% in timber line areas, but more than 90% in the Arctic (Beschel 1969). Arctic birds and mammals must be prepared to face seasons when their offspring can die or when environmental conditions prevent egglaying. Many species are therefore so called K-strategists. K- strategists have relatively long life-spans, but many reproductive seasons during their lives. They can therefore afford to lose offspring in some seasons. Arctic animals are often able to switch between food sources as opportunities change, and to utilize broad niches.

Ecosystem tolerance and stability comparisons

An interesting collection of articles on ecological tolerance was presented by Wiman and Holst at the University of Lund in 1982. Efforts were made to quantify and systematize variables which determine the impacts of perturbations upon different ecosystems and to describe and quantify energy flows and interrelations between components. If we put this information together, we can compare the stability, or vulnerability between ecosystems.

1. Decreasing risk of instability after perturbation: oceans, rivers, lakes, tundra, salt marshes, tropical rain forests, grasslands, and temperate forests.

2. Increased time to respond to perturbation: rivers, oceans, tropical rain forests, lakes, salt marshes, grasslands, temperate forests, tundra.

3. Increased resistance against perturbation: rivers, oceans, lakes, tundra, salt marshes, tropical rain forests, grasslands, temperate forests.

4. Increased ability to recover after perturbation: rivers, lakes, tropical rain forests, temperate forests, salt marshes, tundra, oceans.

Adaptations to the arctic-species level

Let us now consider the statement that arctic plant and animal species must struggle to survive in the extremely harsh Arctic environment, and that they therefore are particularly vulnerable. Are arctic plants and animals less fit for survival in their environment than are species living under more favorable conditions on other latitudes? Are marginal life conditions the explanation of the low diversity? How well adapted are plants and animals to the arctic environment? I will first present the results of some studies of Arctic plant species (Wielgolaski 1985).

Plants which live in the Arctic must be able to grow and to reproduce under extreme environmental conditions and low temperatures. The different species have chosen different strategies. Many mosses and lichens, but also flowering plants, are able to have a net photosynthesis at very low temperatures, and sometimes even when ambient temperatures are below freezing.

The lichen species Cetraria nivalis is able to grow even at temperatures as low as -20^{0}C. Some mosses can grow and continue their photosynthesis down to -10^{0}C. Many flowering plants are also able to grow when temperatures are as low as -5^{0}C. Some flowers are able to turn against the sun and to follow the suns wandering across the sky through the day. Root systems are adapted to cold environments. Growth can be maintained at temperatures close to freezing. Nutrients can be accumulated and stored in the roots and leaf bottoms for several years, until the environmental conditions are sufficiently favourable to permit flower formations. It may take more than one year from flower buds start to grow, until flowers develop and seeds are formed.

The arctic poppy (Papaver dahlianum) is a good example of how different mechanisms are used in order to utilize available light and solar heat for growth and reproduction. The flowers have a parabolic form which collects maximum amounts of light and heat to its center. Studies have shown that temperature differences between the air and the centre of the flower can be considerable. The white or yellow colour of the flowers may add to the efficiency of heat and light collection. The polar poppy has almost horizontal leaves, particularly in the spring when growth is important. Because the horizontal leaves are close to the ground, an increased temperature in the leaves is obtained because more heat is normally emitted from the ground than from the air. Formation of small "cushions" adds to the heat conservation in the poppy and in other species.

Many arctic plants have a very rapid growth in spring, immediately after the snow-melt. In some cases, growth can even start before the snow has melted, because light is able to penetrate some centimetres of snow cover, and because many arctic plants can have photosynthesis when the ambient temperature is close to freezing and sometimes even below freezing. The strategy is often continued growth of small leaves formed the previous autumn, which are protected by scales and sheats. Nutrients are available in roots and leave bases from last year's autumn, to provide for the fast growth which is necessary. As part of this rapid growth strategy, arctic plant roots are often different, depending on the nature of the locality on which they grow.

Grasses and sedges which grow in very wet ground in the Arctic stand often single and develop long shoots (rhizomes) in the soil. On dry ground, such plants are tufted with little or short rhizomes. The short growing season can also be a logical explanation for the amount of non-green biomass compared to the green parts of the vegetation. The non-green parts of the plants can grow even without light, and thereby prepare the rest of the plant with energy reserves for a rapid above-ground growth as soon as the conditions are favorable.

On lower latitudes, the transport of nutrients between the root and above-ground parts of the plants is important, and occurs every autumn and spring. Arctic plants can often not afford such energy consuming transport, because of lack of solar energy and because of the short growing season. One strategy is therefore to keep the green leaves all year, as seen in many polar desert grasses. Even if leaf tips can be dead, or if colours of leaves turn yellow or red in the autumn, they are able to again change colour and maintain photosynthesis the following spring. The plants thereby get a flying start with their photosynthesis when the light returns and growth can start in the spring.

Land living insects can survive the extreme winter cold in the Arctic, because their body cells often contain anti-freezing components which permit super-cooling of the tissues. However, poikilotherm vertebrates cannot survive at all in the Arctic. Their blood and tissues will freeze as the temperature drops below freezing point. Homeotherms, i.e. animals which maintain a relatively constant deep body temperature can survive, however, even if ambient temperatures sometimes change drastically.

Insulation against the cold is a key issue for all arctic warm blooded animals (Fig. 4). There is a correlation between fur thickness and body size in the Arctic. Fur thickness and insulation efficiency increase with the weight of the animals, up to about 5 kg. There can be a gradient of 70^0C or more between skin and air temperatures. Arctic small mammals can partly solve their heat conservation problem by seeking shelter in burrows and nests. They can also utilize the excellent insulative properties of the snow. Temperatures can be as low as -30^0 C in the air, but it is normally only around freezing in the network of tunnels dug by the small rodents close to the ground (Irving 1972). However, the energy drain is so high in the winter, that nearly all arctic warm-blooded animals must lower their general activity level in cold weather. Low ambient temperatures require increased metabolism in order to maintain a constant deep body temperature. Consequently, the animals must burn more fat which is stored in their bodies, or eat more. Therefore, arctic animals avoid all unnecessary activities during the winter. Almost all their time is spent resting or feeding. It is common that arctic birds and mammals lose body weight during the winter, because energy requirements are so high that it can not be maintained by normal feeding. Small arctic rodents can lose as much as 40% of their maximum summer weight during the winter (Irving 1972).

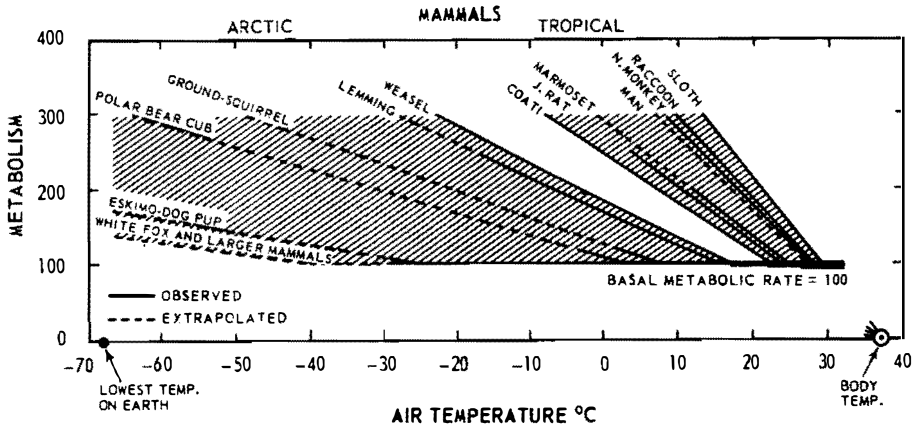

Fig. 4. Heat regulation and temperature sensivity in arctic and tropical mammals. From Irving (1972).

Bird feathers are also very efficient insulators against the cold. The plumage of resident arctic birds tends to be dense and therefore a better insulator than that of migratory birds. Birds can reduce their heat loss in really low temperatures by fluffing and erecting their feathers. When they also pull their legs up under the belly and protect the head under the feathers on the back, they make the most possible out of their plumage, and look like almost completely round feather balls (Fig. 5). But even if the snow can offer some protection, the birds can not utilize it as efficiently as the lemmings hiding under one metre of snow or more during the winter (Irving 1972). Temperatures in hollow trees or other shelters do not differ very much from outside air temperatures. Many arctic birds therefore face serious problems in their efforts to maintain their body heat. Particularly the small bird species have problems during the arctic winter nights. Their plumage is less efficient than that of larger birds, simply because the feathers are smaller and less dense. Besides, small birds have a higher metabolic rate than large birds. They need food more often in order to support their energy requirements and to stay alive. The energy drain can be so high in some small birds under extreme cold temperatures that they would die if they could not compensate for it one way or another. One possibility is to increase metabolism and thereby the heat production in order to compensate for heat loss. Shivering is one way to do it. That means more muscle activity, which yields more body heat. But that leads to a higher energy consumption, which again requires more food. And that can be a problem, particularly in the winter when food is scarce, and when feeding is limited to only a few hours of daylight.

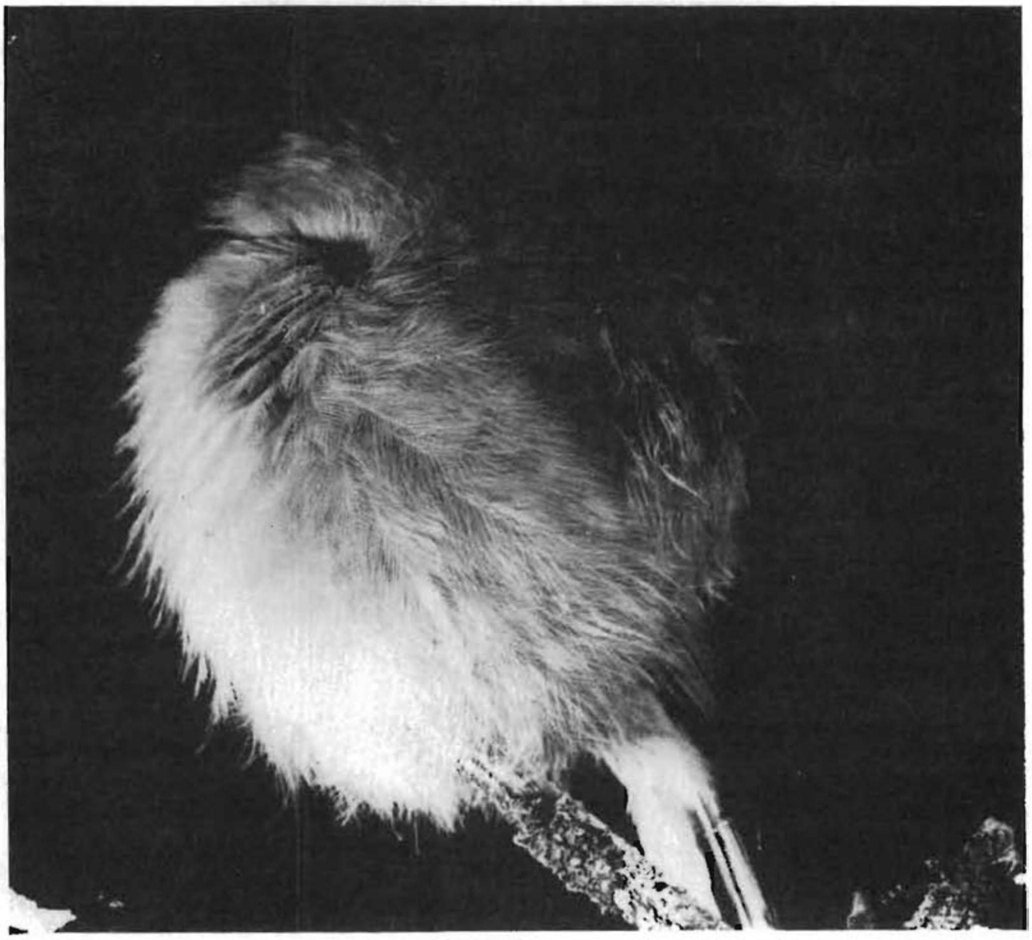

Fig. 5. Arctic small birds erect their feathers, and hide their heads under their wings when temperature falls, in order to minimize heat loss. Photo: A.V. Andreev.

Another possibility is to lower the metabolic rate by lowering the body temperature. What this really means is that some birds are able to enter a state at night which can be compared with hibernation.
It has been shown that tits and other small arctic birds may lower their normal body temperatures with almost 10^0 C when ambient temperatures fall to - 20^0C. The result is energy savings which can be as high as 15 to 30%. When small arctic birds combine several energy saving methods, as fluffing of feathers, seeking shelter, and lowering of metabolic rate, they can save as much as 50% of their normal energy consumption (Reinertsen 1983).

Under the soles or paws of arctic animals, the skin temperature is normally only slightly above freezing. This means that the feet of arctic animals maintain a temperature high enough to prevent freezing and damage of the tissue, but low enough to prevent melting of snow and ice and consequent body heat loss. Arctic birds and mammals have what is commonly called a counter-current system in their legs. This causes a gradually cooling of legs and feet which is necessary in order to avoid tissue damages. And the system ensures that only very little body heat is lost to the environment (Irving 1972). Counter-current systems are also present in the nose of some arctic mammals, e.g. the reindeer. Cold air which is inhaled by the reindeer passes thin blood veins in the nose and is warmed up before it reaches the lungs. Warm air which is exhaled gradually gives off heat as it passes the same blood veins before it leaves the body. The net result is the same as in the legs of arctic mammals and birds. The heat and water are conserved within the body, and only a minimum is lost to the environment.

All arctic marine mammals, and some arctic ungulates, like the

Svalbard reindeer (Rangifer tarandus hyperboreus), have a blubber layer under the skin, which can sometimes be almost 10 cm thick. The blubber is an important insulation against cold water, since hair is unable to give adequate protection there. It serves two functions in the reindeer. It is an important additional protection against cold during long and very cold winters. But it is also a nutritional reserve for the animal. Ptarmigans also have large fat deposits which they can utilize in a similar way during the winter. Like other resident arctic animals, these two species are as inactive as possible when tempereatures are low, and they rest almost continuously when they are not feeding. In this way, they can save energy.

Low connectance between species - some examples from Svalbard

The Svalbard reindeer prefer lichens and grasses for food when conditions are good, but can also utlize mosses when food is scarce. The polar bear (Ursus maritimus) diet consists normally almost entirely of seals in high arctic areas. But they can also eat seaweed, grasses, and may even capture birds on the sea or salmons in the rivers if seals are unavailable. The arctic fox (Alopex lagopus) normally feeds upon lemmings and small rodents in most areas. Such animals are lacking in Svalbard, however, and arctic foxes there must therefore feed upon seabirds in the summer, partly upon ringed seal pups in the spring, and must utilize caches and carrions, or scavenge on dead animals or seals killed by polar bears, in the winter. Falcons, snowy owls and other predatory birds are lacking as breeders in Svalbard, probably because of the absence of lemmings and other small rodents. The large glaucous gull (Larus hyperboreus) has taken over the role as main bird predator, and feeds upon little auks, eider chicks, bird eggs, and act as scavenger.

Conclusions - tropics versus arctic differences in strategies.

The common result of ecological research and modelling in recent years is that a full understanding of the many mechanisms and relationships which govern ecosystems, is required in modern management and conservation. We have only recently become aware of the fact that the lush and diverse tropical ecosystems by no means are more able to cope with severe environmental impacts than are other ecosystems. The tropical rain forest can afford relatively high specialization, high species diversity and high connectance between species, because natural variations in environmental conditions are normally small. The rain forest can tolerate small fires, and other small scale catastrophies, and recover from it. However, if the ecological and environmental conditions are drastically changed, e.g. by total removal of large forest areas, then the consequences can be serious indeed. Plants and animals which are dependent upon the dense forest, and which are strongly connected, are unable to survive any more.

Arctic plants and animals are, on the other hand, true opportunists. Although they live under extreme environmental conditions, they are well adapted for survival. As individuals, they can normally tolerate large fluctuations in climatic conditions. Many animal species can survive for long periods with lack of food, or they are able to utilize a wide variety of food sources. That does not mean, however, that arctic ecosystems can tolerate everything. Let me remind you about the detrimental results from the tracked vehicles over the tundra, which I showed you earlier in this lecture. This kind of ecosystem damage is just as bad as the laterite formation which results from the removal of the tropical rain forest.

Comparative results - different reasons

However, the reasons for the seemingly comparable negative effects are different. The nutritional reserves in a tropical rain forest are almost entirely tied up in the biomass, and is made available by a fast turnover. Removal of the forest will prevent revegetation because of lack of nutrients in the soil. Heavy rains can therefore wash out the terrain and cause erosion. In the Arctic, revegetation is normally not prevented because of lack of nutrients in the soil. But here, the plant growth is slow. The removal of the insulative vegetation cover results in long exposure of the permafrost, and therefore increasingly deeper thawing of the ground, and consequent erosion. The visible end result is the same as in the tropics: serious and seemingly irrepairable terrain damages.

Nature is able to develop ecosystems which through different strategies are able to adapt to varying conditions with great success. Natural ecosystems have evolved along different paths which all have their strengths and weaknesses. It is not my objective to suggest that arctic ecosystems are less vulnerable than ecosystems on other latitudes, or less vulnerable than what we previously thought. My main point is that different ecosystems function with different strategies under different conditions, and that they all have their limitations. The scientific arguments which are often used by ecologists when they discuss ecosystem vulnerability can often be wrong, however.
Modern scientific literature reveals that ecologists have traditionally

used arguments which they "buy" without any question about their validity. A proper management of living resources must be based upon good scientific knowledge, and upon a proper understanding of the ecological processes which govern and which drive any ecosystem on any latitude.

REFERENCES

Anon. 1973: Naturvern på Svalbard. NOU 1973, 19. Universitetsforlaget, Oslo. 14 pp.

Anon. 1982: Miljøvern, kartlegging og forskning i polarområdene. St. Meld. 26 (1982-83). Miljøverndepartementet, Oslo. 68 pp.

Beschel, R. E. 1969: The diversity of tundra vegetation. IUCN Publication New Series 10: 85-92.

Elton, C. 1927: Animal ecology. Sidgwick and Jackson, London. 209 pp.

Gardner, M. R. and Ashby, W. R. 1970: Connectance of large dynamic (cybernetic) systems: Critical values for stability. Nature 228: 784.

Goodman, D. 1975: The theory of divsersity- stability relationships in ecology. Quarterly Review of Biology 50(3): 237-266

Irving, L. 1972: Arctic life of birds and mammals. Springer Verlag, New York. 192 pp.

MacArthur, R. 1955: Fluctuations of animal populations, and a measure of community stability. Ecology 36(3): 533-536.

May, M. R. 1972: Will a large complex system be stable? Nature 238: 413-414.

Pimm, S. L. 1984: The complexity and stability of ecosystems. Nature 307: 321-326.

Reinertsen, R. E. 1983: Nocturnal hypothermia and its energetic significance for small birds living in the arctic and subarctic regions. A review. Polar Research 1 n.s.(3): 269-284.

Remmert, H. 1980: Arctic animal ecology. Springer Verlag, New York. 250 pp.

Vibe, C. 1967: Arctic animals in relation to climatic fluctuations. Medd. om Grønland 170(5). 227 pp.

Wielgolaski, F. 1985: The green arctic. In F. Bruemmer (ed.) The Arctic of the World. Key Porter Books, Toronto. In print

Wiman, B., and Holst, J. 1982: Ekologisk tolerans. Om stabilisering och foranderlighet i ekologiska system. Naturressurs- och Miljøkomiteen, Bakgrundsrapport 11. Departementenes reprocentral, Stockholm. 242 pp.

Wolda, H. 1978: Fluctuations in abundance of tropical insects. The American Naturalist 112(988):1017-1045.