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4.4 *Effects in Arctic and Subarctic Systems*

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4.4.1 COLD-ENVIRONMENT ECOSYSTEMS

The features dominating cold-climate ecosystems are primarily those of low energy fixation and harsh environmental conditions. In terms of energy, the sun is low in the horizon at the best of times, and its radiant energy strikes the earth a 'glancing blow'. In addition, the high albedo of the snow causes a good deal of solar radiation to be immediately reflected. The growing season is short, and plants must mature quickly to reproduce. Thus they are uniformly small, and productivity is low, ranging from a few per cent to less than half of one per cent of the corresponding crop in a temperate climate. Adaptation mechanisms are abundant; one finds plants growing in rosettes and cushions, storing much more of their energy in roots than their temperate counterparts, developing waxy cuticles, and so forth. Nonetheless, since they have no way to escape or hide from conditions, as hibernating animals can, the plants are generally under extreme stress and the ecosystem has practically no 'resilience' in the ecological sense.

The decreased primary production is the fundamental limitation of the cold-environment ecosystem. Such animals and birds as choose to live there generally have adaptation mechanisms that are quite effective, as long as the food supply is adequate. Some, like the bear and caribou, develop heavy lipid layers and extremely effective fur to prevent energy loss. Some simply migrate to warmer regions; some small animals live under the snow cover, which is itself rather effective insulation; and some hibernate, thus decreasing their energy requirements sharply.

There are other effects of the arctic and subarctic environment which are not nearly so well understood. For example, for a large part of the year arctic plants and animals receive sunlight that is not only in short supply, but also has a different wavelength distribution, losing energy in the blue regions because of the effectively greater thickness of the atmosphere when traversed at a slant. The magnetosphere surrounding the earth is to some extent 'open' at the poles, so that these regions receive a greater radiation burden. Also, northern regions will typically experience intense geomagnetic activity, which may have effects as yet unknown. Studies in man have shown deleterious effects of the lack of solar regularity; numerous internal biological clocks are desynchronized, with observable behaviour changes resulting; there is no reason why other inhabitants of the high-latitude environment should be spared.

In summary, we observe that cold-climate ecosystems are characterized by their low productivity, at the level of primary energy incorporation, and that they are among the most stressed ecosystems on earth. This means that any further stress, such as chemical pollution or physical disturbance, may be assumed at the outset to have profound influences on the ability of such systems to survive at all, let alone to recover; in any case, recovery will be slow.

4.4.2 CHEMICAL PERSISTENCE

Two factors interact to increase the length of time that a chemical will persist in the same chemical form, as opposed to an increased residence time, in a cold environment. Firstly, any chemical process will proceed more slowly at decreased temperatures, and secondly, bacterial and similar biological degradation processes will typically be reduced because of the generally decreased biotic activity of the microenvironment of the pollutant.

The simplest way to describe the first factor is in terms of the Q-10 rule, the handy (and surprisingly realistic) rule of thumb that a chemical reaction in general will very roughly change its rate by a factor of two when the temperature changes by ten degrees Celsius. Thus if the average ambient temperature is 10°C rather than 25°C, the rate of degradation by a pure chemical process will decrease by a factor of 2.8, which would mean that a chemical which naturally degraded with a half-life of, say, four days, would now have a half-life of 11 days approximately.

Naturally, this calculation is only a rough guide; the actual degradation process involves other factors, such as photolysis, presence of other chemicals, and so forth. Details of such calculations, taking into account these and other factors, have been published, and in fact interactive computer programs are available (NRCC, 1981; Burns *et al.*, 1981) by which numerical and graphical representations of these processes can be generated at will. The basic result does not change, namely that in a cold environment the degradation rate is significantly slowed, and this of course means that other processes which may be time-limited, such as transport, entry into a water supply or a food chain, or the process of biomagnification itself, will routinely have more time available in which to take place.

4.4.3 BIOACCUMULATION AND EXPOSURE

In general, the theme explored above recurs in this section also; in a cold climate the special considerations of the environment interact with any chemical pollutant to make its effects more serious than would be the case for the same substance in a warmer climate. This is true for uptake, food-chain concentration, and behaviour in the organism, for perhaps a series of different reasons.

4.4.3.1 Uptake

We have previously argued that cold conditions will mean that more of the polluting substance will be close to ground surface or actually carried on the emergent part of plants. This immediately means that grazing animals will pick up more of the chemical. There is a second effect, however, namely that in the North, with its lower per hectare productivity, animals tend to graze more completely, leaving very little of the above-ground plant material behind. This factor increases still further the faction of the deposited material that immediately enters the body of grazing animals. In some (albeit rare in the North) conditions, i.e. with a low wind, leafy vegetation, and recent pollutant input, uptake by grazers can be virtually complete.

To this, of course, we have to add the previous consideration that the chemical, when ingested, is more likely still to be in its original form rather than already partially degraded.

4.4.3.2 Food Chains

The main feature of cold-climate food chains is that they are less complex than their temperate counterparts. Instead of complex ‘webs’, with several shared or alternative food supplies at each trophic level, the food chains tend to be linear. This means that animals often have no choice of food; if the lower trophic level is somehow contaminated, even to the point of being objectionable to the grazer or predator, the choice is simply to consume it or eat nothing at all. This also, of course, makes the entire ecosystem more vulnerable since the whole structure may collapse if a single species is eliminated or even seriously depleted.

4.4.3.3 Behaviour in an Organism

We should also briefly mention a feature of cold-weather mammals that increases their vulnerability (the same general idea applies also to fishes and birds). This is connected with the abundant fat deposits many of them accumulate, both for insulation against the cold and in some cases as food supplies for hibernation. Many of the chemical pollutants in our environment are lipophilic. When ingested and distributed around the body of an animal, they will associate with the lipids and remain there, generally doing the animal relatively little harm. However, the large quantities of fatty tissue do allow the accumulation of large quantities of these chemicals.

The problem arises when the animal is forced to use its lipid reserves, either during hibernation or during a period of hunger or starvation for other reasons, sometimes environmental and sometimes behavioural, such as migration—a very energy-dependent process—or perhaps associated with the increased burden of the breeding season, e.g. nest-building or the like. During such periods, the lipids are metabolized and the chemical can be freed to come into contact with more sensitive organs. The animal, in effect, receives a major dose all in one shot; moreover, this may come at a time when the animal is already stressed by other factors. The same observation may be made of fish, which lose a great deal of their energy reserves during the hungry winter months under the ice.

We should note that this stress may also occur just when young are being raised, as in nesting birds, decreasing the ability of the parents to provide adequate food for the nestlings. In the case of bears, where the young are born and nursed during hibernation, the increased exposure to the young through milk is also obvious.

4.4.4 EFFECTS ON SPECIES AND ECOSYSTEMS

Individuals suffer from toxic chemicals rather more under cold conditions than elsewhere for several reasons. Two of these have been mentioned already, namely the fact that they are already under substantial stress because of the harsh conditions, and also because of the possibility of sudden large exposures resulting from the release into the environment of stored-up quantities of pollutant, or the sudden release of toxic agents into their own bodies when stored lipids are mobilized.

In addition, we have pointed out that the simplicity of the food webs makes for less variety in diet. This is also true, of course, for humans; people living in cold climates tend to have a much less varied diet than others. In many cases, consumption of top carnivores, such as large fish or seals, is dominant, so that bioaccumulation through the food chain has a chance to have maximum effect. Possibly the people of the North consume a larger amount of food from the top of the food chain than any other people on earth, and the exposure to such chemicals as mercury and DDT from eating such a selection of food is well known.

There are also cultural influences by which highly nutritious or otherwise preferred food is selectively consumed, sometimes by particular parts of the population. Perhaps the most outstanding example of this is the Inuit population of northern Canada, in which seal liver is selectively and traditionally reserved for consumption by pregnant women. The liver, unfortunately, contains very high concentrations of mercury, far higher than in other tissues of the same animal or in alternative foodstuffs, such as fish. (One of the intriguing questions that has not been fully resolved is why this practice does not produce more cases of mercury poisoning that it does; one current theory is that because the liver tissue also contains large quantities of selenium, known to be protective against mercury poisoning, damage is avoided. In any case, the author is not aware of any documented cases of overt mercury poisoning in this population.)

There are many other examples of how toxicity of an agent can be enhanced by low temperatures. The toxic effects of oil spills on sea birds are enhanced at low temperatures (Levy, 1980), probably because the thermal insulation efficiency of feathers is decreased. The development time of invertebrates is sharply dependent on temperature (Rosenberg and Costlow, 1976); other examples have been noted.

At the species level, interaction with cold can enhance effective toxicity, first of all, simply because the entire species is already in a stressful situation. More specifically an entire species can be wiped out because of elimination of the species (perhaps only one) below it in the food web. Alternatively, a decrease in the size of a population below the level at which predation normally takes place can increase predation pressure, as the higher organism increases the effort level to find food and ends up consuming the entire crop or population. This has been observed to happen locally with lichens, which are grazed by caribou; a decreased population of lichens, thought to be due to acidic precipitation, was almost wiped out by a too large population of caribou in the region.

Finally, at the level of the ecosystem, the entire structure is more delicate for a variety of reasons already covered. The simplicity of the food web means that elimination of one species can destroy all those above it, and even relatively small perturbations will require quite a large recovery time.

Scarcely any measure of ecosystem performance can be imagined that is not made more sensitive to additional stress by a cold environment. This is not, of course, surprising; with decreased energy input, increased requirements for basic existence, and decreased diversity, however measured, it must be obvious that the ecosystem will be less able to absorb and recover from additional insult. What is perhaps not always realized is that there is a dual effect in that transport and persistence of chemicals take place in such a way that their effects are enhanced, and environmental conditions may easily convert a low-level chronic exposure into a brief but serious dose. The message is that great care must be taken to protect cold-climate ecosystems, and information gained by the study of temperate regions is very often not relevant.

4.4.5 REFERENCES

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