Environment and health: 7. Species loss and ecosystem disruption — the implications for human health

Review

Synthèse

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This article has been peer reviewed.

CMAJ 2001;164(1):66-9

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There is abundant evidence that human beings are beginning to alter some of the planet's basic physical, chemical and biological systems,[1–3] endangering other species and disrupting ecosystems in the process[4] and ultimately threatening human health.[5–7]

When *Homo sapiens* evolved some 120 000 years ago, the number of species on Earth was the largest ever,[8] but human activity has resulted in species extinction rates that are currently 100 to 1000 times the pre-human rate.[9] Although the record demonstrates that humans hunted to extinction scores of large mammals and birds as early as tens of thousands of years ago,[10,11] it is only in recent times that these extinctions have spread to virtually every part of the planet and to almost every phylum. Species numbers are now being reduced so rapidly that some experts have predicted that 25% or more of all species currently alive may become extinct during the next 50 years if these rates persist.[12,13] Such losses have prompted biologists to refer to the present period as "the sixth extinction"[14] (the last great extinction event, the fifth, was 65 million years ago, at the end of the Cretaceous period, when dinosaurs became extinct) and to warn that evolutionary processes would not replace these losses with a stock of new species for several million years.[15] From this perspective, the loss of species may be said to be the most destructive and permanent consequence of human-caused degradation of the global environment.

Global climate change,[16] stratospheric ozone depletion,[17] chemical pollution,[18] acid rain,[19] the introduction of alien species[20] and the overhunting of species[21] all threaten biodiversity, but it is the degradation, reduction and fragmentation of habitats that is the greatest threat, particularly in species-rich areas such as tropical rain forests and coral reefs.[22]

The relation between human health and the health of other species has been given little attention by scientists and public health experts and has not been a part of medical education. This article reviews some of the ways that plant, animal and microbial species support human health and, by their interactions with each other and with nonliving components of the environment, produce what are called "ecosystem services," which make all life, including human life, possible on Earth. Understanding these connections will be increasingly important to physicians and other health care professionals in coming decades, as the number of species driven to extinction continues to mount.

Potential medicines

We are losing plants, animals and microorganisms, perhaps most of which are still undiscovered, that may contain valuable new medicines. Only about 1.5 million species have been identified,[23] but there are thought to be 10 or even 100 times that number.[9] Over the course of millions of years of evolution, species have developed chemicals that have allowed them to fight infections, tumours and other diseases and to capture prey and avoid being eaten, chemicals that have become some of today's most important pharmaceutical agents. Organisms in tropical rain forests, for example, have given us *d*-tubocurarine (from the chondodendron vine), quinine and quinidine (from the cinchona tree), vinblastine and vincristine (from the rosy periwinkle plant), and erythromycin, neomycin and amphotericin (from soil microbes). Species from temperate zones have yielded some of our most useful drugs as well: ASA was originally extracted from the willow tree and digitalis from the foxglove plant. Medications have also been developed from marine species; for example, cytarabine, from a Caribbean sponge, is the single most effective agent for inducing remission in acute myelocytic leukemia.[24] A recent survey of the 150 most frequently prescribed drugs in the United States demonstrated that 57% of them contained compounds, or were patterned after compounds, derived from non-human species.[25]

Two examples of recently developed drugs, one from a plant and one from an animal, deserve mention.

The story of taxol and the Pacific yew illustrates how we may be losing new medicines before species have been analyzed for their chemical content. The commercially useless Pacific yew was routinely discarded as a trash tree during logging of old growth forests in the Pacific northwest region of the United States until it was found to contain the compound taxol, a substance that kills cancer cells by a mechanism unlike that of other known chemotherapeutic agents: it prevents cell division by inhibiting the disassembly of the mitotic spindle.[26] The discovery of the complex molecule taxol and its novel mechanism of action has led to the synthesis of several taxol-like compounds that are even more effective than the natural compound,[26,27] which illustrates how a clue from nature can lead to the discovery of a new class of drugs that would have been extremely difficult to discover in the laboratory. Early clinical trials revealed that taxol was able to induce remission in cases of advanced ovarian cancer unresponsive to other treatments;[28] subsequent experience has shown that taxol may be one of the most promising new drugs available for the treatment of breast and ovarian cancer.[27]

The other example that deserves mention is the peptide compounds in the venom of cone snails, a genus of predatory snails numbering about 500 species that inhabit tropical coral reefs. The diversity of these compounds is so great that it may rival that of alkaloids in higher plants and secondary metabolites in microorganisms.[29] Some of these peptide compounds, which have been shown to block a wide variety of ion channels, receptors and pumps in neuromuscular systems, have such selectivity that they have become important tools in neurophysiological research and may become invaluable to clinical medicine. One voltage-sensitive calcium-channel blocker, omega-conotoxin, binds with enormous specificity to neuronal calcium channels and has been found to have potent activity in animals both as an analgesic[30] and as a means of keeping nerve cells alive following ischemia.[31] It is now being studied in advanced clinical trials in its synthetic form (SNX-111, or ziconotide) for the prevention of nerve cell death following coronary artery bypass surgery, head injury and stroke, and for the treatment of chronic, intractable pain associated with cancer, AIDS and peripheral neuropathies.[32] SNX-111 has 1000 times the analgesic potency of morphine but, unlike morphine, does not lead to the development of tolerance or addiction or to a clouding of consciousness.[33] As coral reefs are increasingly threatened in many parts of the world,[34] the existence of reef-dwelling organisms such as cone snails is similarly threatened.

Research models

Species loss also leads to the loss of valuable research models that help us understand human physiology and disease. Biomedical research has long relied on mice, rats and guinea pigs as experimental subjects and on a host of other organisms possessing unique structures or physiologies (e.g., fruit flies and *Escherichia coli* in genetics research, and horseshoe crabs and squid in nerve cell research). Bears, sharks and the microscopic roundworm *Caenorhabditis elegans* are animals that provide examples of the kinds of biological secrets that could be lost to medical science with the loss of the species.

Bear populations are threatened in many parts of the world because of the destruction of their habitats and because of overhunting secondary to the high prices their organs, reputed to have medicinal value, bring on the Asian black market.[35] Bear gallbladders, for example, are worth 18 times their weight in gold. Yet living bears are far more valuable than the sum of all their body parts. For example, during the 3 to 7 months that black bears are denning (a hibernating-like state), they do not eat, drink, urinate or defecate, yet they can deliver young and nurse them, they can maintain their bone density and lean body mass, and they do not become ketotic or uremic.[36] Osteoporosis has been found to occur in all other mammalian species studied, including humans, during periods of immobility or a lack of weight bearing.[37] Understanding how bears prevent bone resorption could lead to new ways of preventing and treating osteoporosis. Similarly, learning how hibernating black bears avoid becoming uremic by converting urea into protein could help in the development of effective treatments for renal failure.[38]

Why sharks, the first vertebrates to have developed antibodies and a full complement of immune proteins, have reduced rates of infections and tumours has prompted intensive investigation into the nature of their immune systems.[39,40] The answer may be in part that sharks produce powerful infection- and cancer-fighting molecules in their tissues that boost their immune response. One such substance isolated from sharks, an aminosteroid named squalamine, has prevented the growth of solid tumours in a number of animal models, most likely because of its angiogenesis-inhibiting ability,[41] and it has shown broad-spectrum antibiotic activity against gram-negative and gram-positive bacteria (with a potency comparable to that of ampicillin) and against certain fungi and protozoa.[42] Because some shark species are endangered by overfishing and the demand for shark fin soup and shark cartilage, our ability to understand their unique immune systems could be endangered as well.[43]

With the mapping of the complete genome of the microscopic roundworm *C. elegans*, scientists have been able to design experiments to learn how the worm's genes control its metabolism of glucose,[44] the mechanisms of its programmed cell death [45] and its longevity.[46,47] Although nematodes and mammals diverged from a common ancestor some 700 to 800 million years ago,[48] the genetic codes regulating these fundamental biological processes seem to have remained surprisingly similar for *C. elegans* and human beings. As a result, studying *C. elegans* may yield important insights into human diabetes, obesity, diseases in which there are disturbances in programmed cell death (e.g., cancer, autoimmune disease and neurodegenerative states) and aging.

Ecosystem services

An ecosystem is the sum of all the species and their actions and interactions with each other and with the nonliving matter in a particular environment. How ecosystems provide the services that sustain all life on this planet remains one of the most complex and poorly understood areas of biological science.[49,50]

Ecosystem services include such vital functions as regulating the concentration of oxygen, carbon dioxide and water vapour in the atmosphere, filtering pollutants from drinking water, regulating global temperature and precipitation, forming soil and keeping it fertile, pollinating plants, and providing food and fuel.[49,51]

One critically important service is the role ecosystems play in controlling the emergence and spread of infectious diseases by maintaining equilibria among predators and prey, and among hosts, vectors and parasites in plants, animals and humans. This protective function of biodiversity has only recently begun to be appreciated.[52–55] Examples of human infectious disease that can be affected by upsetting these equilibria include malaria and leishmaniasis through deforestation;[56] Lyme disease through changes in the number of acorns and in the populations of black-legged ticks, white-footed mice and white-tailed deer;[57] Argentine hemorrhagic fever through the replacement of natural grasslands with corn monoculture;[58] and cholera through increased algal blooms, secondary in part to warming seas and to fertilizer and sewage discharge.[59]

The hantavirus pulmonary syndrome outbreak in the southwestern United States provides a valuable model of how altered numbers of a species carrying an infectious agent can result in the emergence of a lethal human infectious disease. Six years of drought in the Four Corners area (the region in southwestern United States where Arizona, Colorado, Utah and New Mexico meet) ended in the late winter and spring of 1993 with unusually heavy snow and rainfall. The drought had reduced the populations of owls, snakes and foxes, the natural predators of the native deer mouse, while the increased precipitation led to a heavy crop of pine nuts and grasshoppers, food for the mice.[60] As a result, there was a 10-fold increase over baseline levels in the deer mouse population. During this period a severe respiratory syndrome developed rapidly in 17 previously healthy people, most of them Native Americans; 13 of them died.[61] It was discovered that the deer mice were carrying a hantavirus that they shed in their saliva and excreta and that, with the greater numbers of mice, there was a greater chance for people to come in contact with them and thus to become infected. This outbreak was triggered by a change in climate, but outbreaks of human infectious diseases might also occur if species numbers are altered in other ways, for example through overhunting of a major predator. It is not known how many viruses or other infectious agents in the environment, potentially harmful to man, are being held in check by the natural equilibria afforded by biodiversity.

Conclusion

Despite an avowed reverence for life, human beings continue to destroy other species at an alarming rate, rivaling the great extinctions of the geologic past. In the process, we are foreclosing the possibility of discovering the secrets they contain for the development of new life-saving medicines and of invaluable models for medical research, and we are beginning to disrupt the vital functioning of ecosystems on which all life depends. We may also be losing some species so uniquely sensitive to environmental degradation that they may serve as our "canaries," warning us of future threats to human health.

Policy-makers and the public may give protection of the global environment their highest priority only after they begin to understand that human health and life ultimately depend on the health of other species and on the integrity of global ecosystems. Physicians and other health care professionals need to learn about the human health dimensions of species loss and ecosystem disruption, for they may be the most powerful voices in helping to promote this understanding.

Competing interests: Dr. Chivian has received honoraria for speaking on the general topic of this article and has received travel assistance from the sponsoring organization of these talks.

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