MOUNTAINS

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6 Animals of the Mountains

JAMES C. HALFPENNY

Islands above the clouds, mountains usually contain isolated pockets of animals quite different from those of the surrounding habitat. The geographical isolation strongly influences the type of animals that live in mountains. Similarities between types of animals in different ranges result not only from common origins but also from similar evolutionary responses to the harsh environment.

Mountain Fauna

The fauna on a mountain can be grouped into alpine, montane, and lowland species. Alpine species—for example, the hoary marmot *Marmota caligata* of North America, the rock hyrax *Procavia johnstoni mackinderi* of Kenya, and the red-eared pika *Ochotona erythrotis* of China—are mostly found above the treeline. Montane species, such as the long-tailed weasel *Mustela frenata* of the Northern Hemisphere, have substantial populations living below the upper treeline but are not well established in the lowlands. Lowland species, such as the white-tailed jackrabbit *Lepus townsendii* of North America, are well established below the lower treeline, but some populations also live high on the mountains.

Opposite. *The bighorn sheep* Ovis canadensis *is among the most commonly seen of all big animals in the mountains of western North America, especially in national parks.*

Jeff Foott/AUSCAPE

Male wapitis (elks) Cervus canadensis *spar for females at the approach of winter. Formerly widespread across North America, wapitis are now effectively restricted to the western mountains.*

It is likely that alpine forms evolved during the Pliocene uplift of Tibet, between five and two million years ago, from a parental stock of lowland steppe animals. During the ice ages, dispersal routes through Arctic tundra areas allowed alpine and montane species to spread west along a relatively continuous mountain chain to the European Alps and to spread east across the Bering Strait to the North American mountains.

Tropical mountains are biologically old and represent evolutionary archives of long-isolated species that differ dramatically from their temperate and polar counterparts. Tropical mountains were never completely covered by glaciers during the ice ages, and dispersal routes to them were few and hazardous. Consequently, many alpine species in Africa and South America appear to have been derived from local lowland species, and different species are found in tropical mountains, such as gorillas *Gorilla gorilla* and the alpaca *Lama pacos*, respectively.

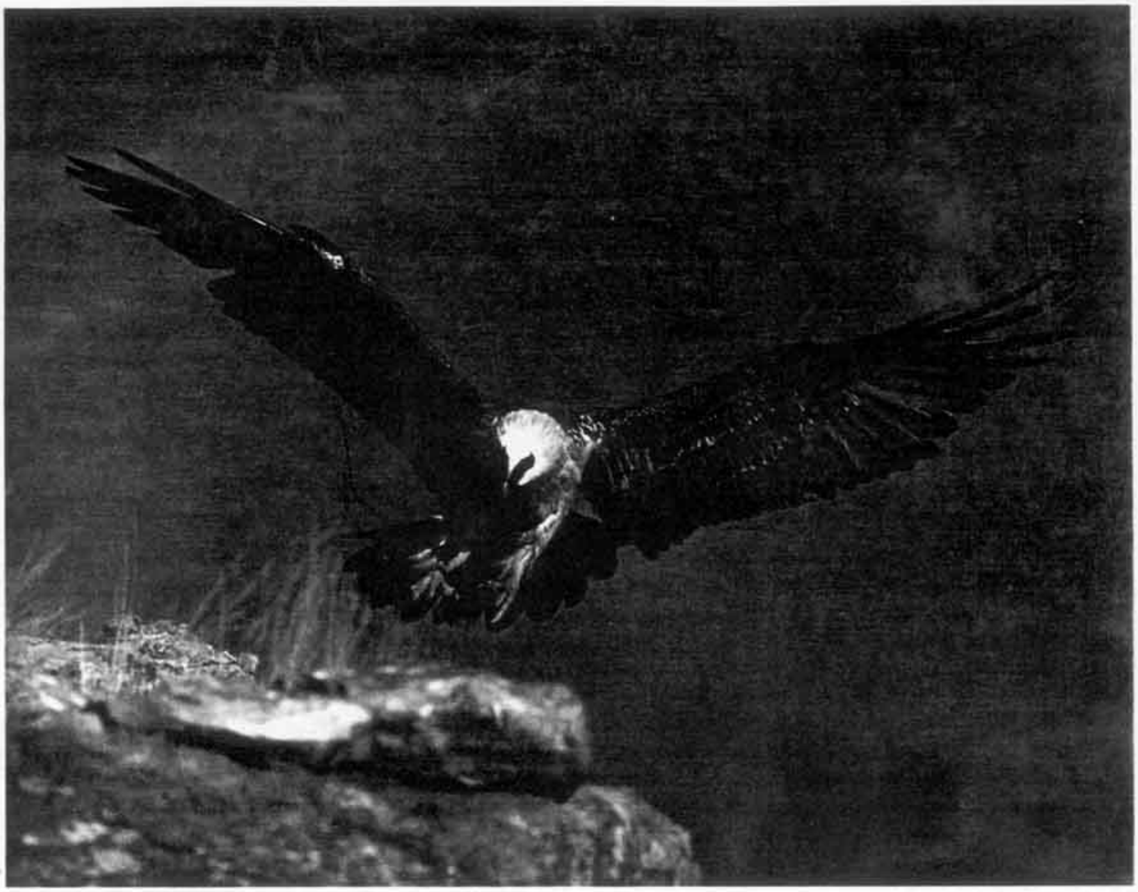
Islands in the Sky

Mountains differ from true islands in that the lowlands around them present a less hostile environment to immigrating species than the ocean, and the transition from lowlands to mountains is less sharp than that from sea to oceanic islands. However, ecological processes governing the number of species and their diversity are similar for islands and mountains. Insularity—the degree of deviation from surrounding areas—increases with the size of the mountain, its biological age, and its distance from other mountains. The greater the distance between mountains, the fewer the successful dispersers, because of the dangers involved in crossing intervening lowlands and the random chance of reaching another mountain. For instance, Mount Kenya is isolated by the African savannah and has many endemic species—species found there and nowhere else. These species have been isolated on the mountain long enough to prevent their interbreeding with similar species elsewhere.

There are four types of mountain colonization: adaptation of lowland species as they move up the mountain; adaptation of lowland species during geologic uplift; chance migration of previously adapted species; and migration facilitated by climatic change, such as periods of glaciation. Extinctions occur on all isolated mountains when chance events, such as disease or climatic change, exceed the ability of species to survive. However, some mountains, such as those of the basin and range country of the American southwest, have become so cut off that colonization no longer occurs. Alpine populations continue to decrease, and the few remaining species form relict outposts.

Martin Colbeck/Oxford Scientific Films

During their annual migrations between China and the northern plains of India, bar-headed geese Anser indicus *cross the Himalaya, where they have been recorded at nearly 10,000 meters (about 32,000 feet), which is approximately the cruising altitude of modern aircraft.*



Nigel Dennis/NHPA

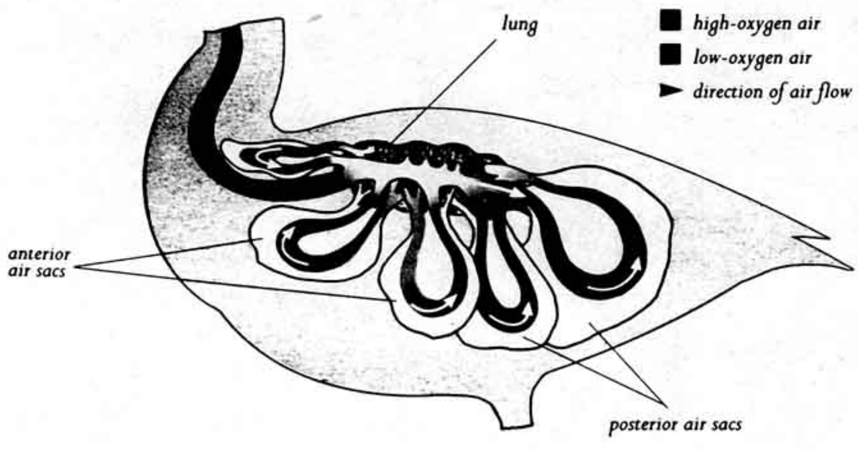
Right. *A lammergeier* Gypaetus barbatus *swoops in for a landing in the Drakensberg mountains of South Africa. Alpine regions suit birds of prey because updrafts and other complex air movements reduce the effort of soaring.*

The birds' unique respiratory system is a key factor in their immunity to the effects of altitude. Unlike the lungs of other animals, the avian lung is set amid a complex system of air sacs arranged in such a way that fresh air flows through instead of into them.

Adaptations to Mountain Living

All animals living at high altitudes, including humans, must overcome the constraints imposed by such an environment: low temperatures, large daily fluctuations in temperature, low relative humidity, strong and persistent winds, low plant production, decreased oxygen, and increased ultraviolet radiation. Of all constraints, the most important are lack of oxygen, water, and food.

THE AVIAN RESPIRATORY SYSTEM



LACK OF OXYGEN

Available oxygen decreases rapidly with increased altitude. At 5,500 meters (18,000 feet) there is about half the oxygen available that there is at sea level, while on top of Mount Everest (8,848 meters/29,029 feet) there is only 30 percent available.

Lack of oxygen is a major stress factor for some animals but not for others. Smaller animals, especially invertebrates, reptiles, and amphibians, seem to be little affected by increased altitude, although invertebrates and amphibians face other constraints against mountain living.

Birds are little affected by altitude, mainly as a byproduct of their efficient respiratory system, which is designed to respond to the dramatically different demands of a warm-blooded body at rest and in full flight. Birds have a network of air sacs scattered throughout the body in a very intricate arrangement. Air passes through the windpipe and through the lungs into the air sacs. Oxygen is transferred during this process. The muscles then contract the air sacs, pushing air back out through the lungs where oxygen is extracted a second time.

Many birds have been reported at altitudes above 6,000 meters (19,700 feet), although little is really known about their high-altitude flights. Tibetan ravens

Corvus corax tibetanus follow mountaineers to their high-altitude camps in search of whatever food scraps they can find. Sir Edmund Hillary reported an alpine chough *Pyrrhocorax graculus* at 8,500 meters (27,900 feet). Himalayan griffon vultures *Gyps himalayensis* also reach that altitude, while bearded vultures, known as lammergeiers *Gypaetus barbatus*, have been reported at 7,600 meters (25,000 feet).

Most remarkable of all, though, is the bar-headed goose *Anser indicus*, which, during its migrations between India and Tibet, may go from sea level to above 9,000 meters (29,500 feet) within a single day as it flies over Mount Everest. Scientists believe that these geese were making their migrations before the Himalaya were uplifted, and that the use of this route today is a behavioral fossil of bygone times. Although the uplift was rapid in geological time, sufficient time was available for the geese to adapt to having to fly the nearly stratospheric route.

Astonishingly, the geese call continuously as they fly over Mount Everest. For humans, talking while walking becomes an effort by 4,300 meters (14,100 feet), and few people have ever climbed any higher than 8,500 meters (27,900 feet) without supplementary oxygen. But geese honk away during their night flights. Scientists are not yet sure exactly why the geese do this, but it has been suggested that the honking may serve as an echolocation device to prevent the birds flying into the mountain.

James Brandenburg/Minden Pictures

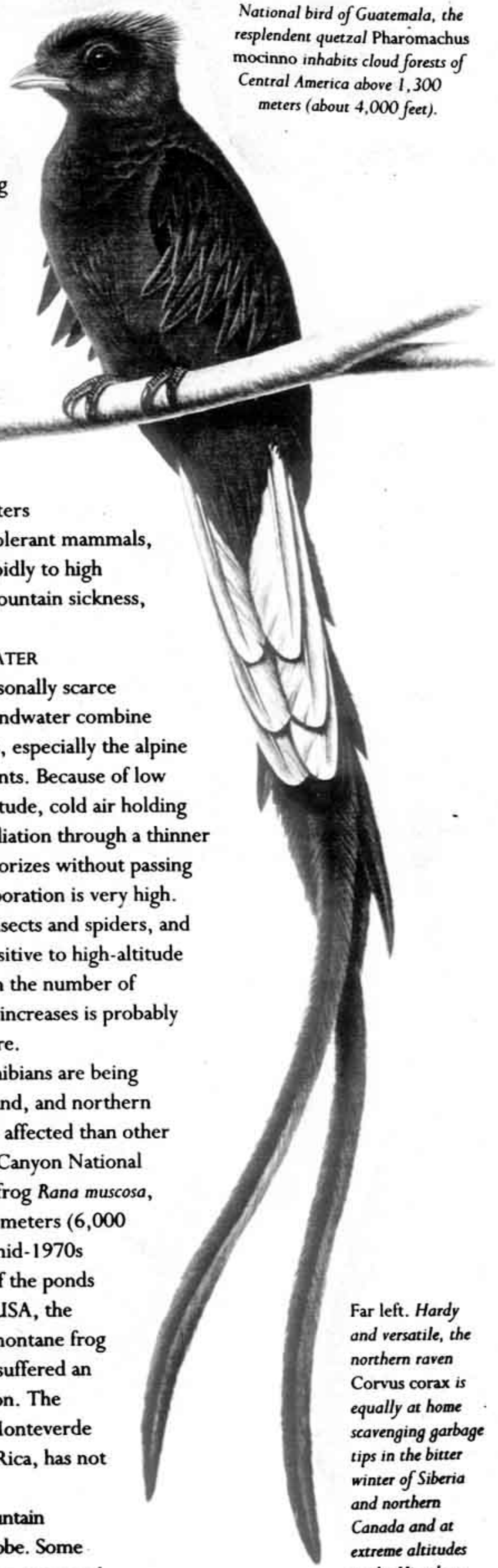
Their very presence proves that some larger animals, such as the yak, have adapted to living with low oxygen levels at high altitudes. However, other animals are definitely affected by the lack of oxygen. Lowland domestic cattle, for example, seem to be limited to altitudes below 3,000 meters (9,800 feet), and permanent establishments of people are limited to 5,500 meters (18,000 feet). If non-altitude-tolerant mammals, including humans, are taken rapidly to high altitudes, they develop acute mountain sickness, which often results in death.

LACK OF WATER

Low atmospheric humidity, seasonally scarce running water, and frozen groundwater combine to make many montane regions, especially the alpine one, extremely arid environments. Because of low water-vapor tension at high altitude, cold air holding less water, and intense solar radiation through a thinner atmosphere, snowfall often vaporizes without passing through a liquid stage, and evaporation is very high. Invertebrate animals, such as insects and spiders, and amphibians are particularly sensitive to high-altitude aridity. The drastic reduction in the number of invertebrate species as altitude increases is probably partly a result of scarce moisture.

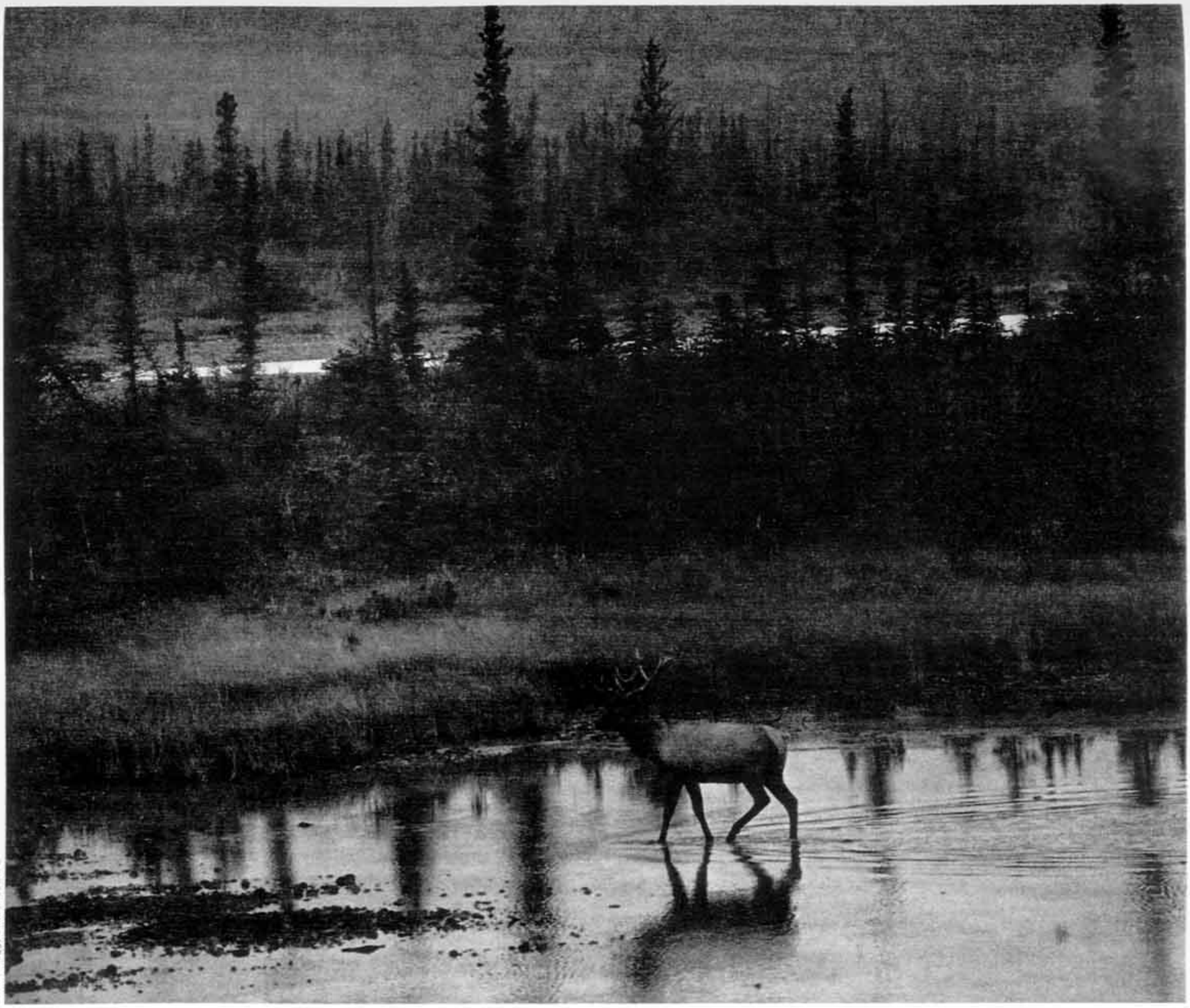
Worldwide declines in amphibians are being reported, but mountain, highland, and northern frogs seem to be more severely affected than other amphibians. In Sequoia–Kings Canyon National Park, California, the montane frog *Rana muscosa*, whose range is 1,800 to 3,500 meters (6,000 to 11,500 feet), has since the mid-1970s disappeared from 98 percent of the ponds it once inhabited. In Oregon, USA, the Cascade frog *Rana cascadae*, a montane frog living around the treeline, has suffered an 80 percent decline in population. The golden toad *Bufo periglenes* of Monteverde Cloud Forest Preserve, Costa Rica, has not bred since 1987.

Few factors would affect mountain amphibians around the entire globe. Some theories include acid precipitation, increased



National bird of Guatemala, the resplendent quetzal Pharomachus mocinno *inhabits cloud forests of Central America above 1,300 meters (about 4,000 feet).*

Far left. *Hardy and versatile, the northern raven* Corvus corax *is equally at home scavenging garbage tips in the bitter winter of Siberia and northern Canada and at extreme altitudes in the Himalaya.*



Erwin & Peggy Bauer/AUSCAPE

Like other deer, the male wapiti sheds and replaces its antlers annually, apparently because they are so frequently damaged in combat that perennial antlers would be reduced to uselessness within a few years.

Opposite. *The complex interaction of temperature, rainfall, cloud-cover, exposure, and slope results in a range of distinct forest types on tropical mountainsides, each with its own distinctive flora and fauna. The golden toad* Bufo periglenes, *for example, inhabits the cloud forests of Central America. It is now feared extinct.*

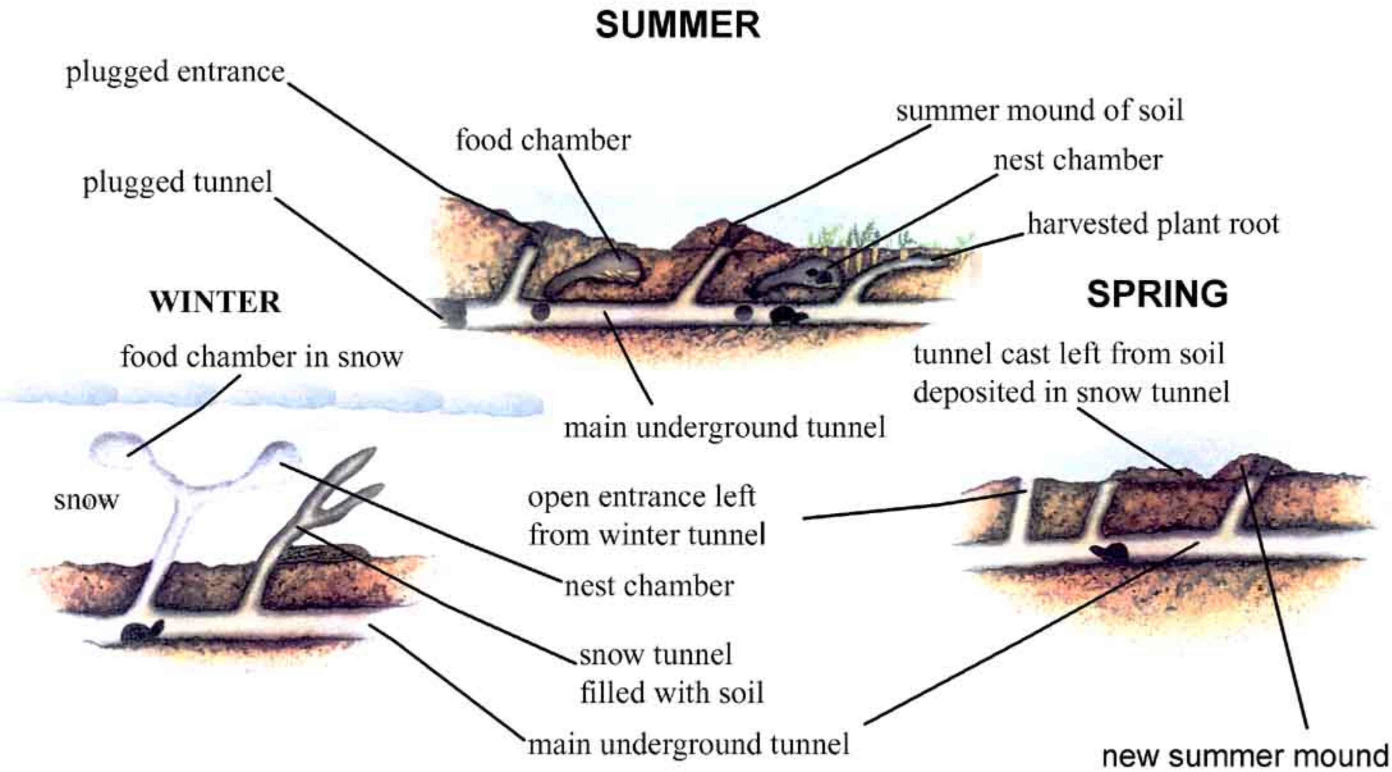
ultraviolet radiation because of ozone depletion in the atmosphere, and general climate change because of global warming ("the greenhouse effect"). Local factors implicated in the declines include drought, pesticide pollution, mining, logging, habitat destruction, and human consumption. The combined impact of local and global changes may exceed the amphibians' ability to adapt and may be signaling the demise of creatures that have survived high on mountains for 100 million years.

LACK OF FOOD

Lack of adequate food limits many species to the lower slopes of mountains. Mountain animals have evolved strategies for dealing with food scarcity. As winter approaches, many species simply migrate out of the mountains. A wapiti (elk) *Cervus elaphus* will lead her herd down from the high country about the time the snow gets 30 centimeters (12 inches) deep. Other animals face winter by hoarding food during the summer. Perhaps the star hoarders are pikas. The American pika *Ochotona princeps* faces the winter food shortage by making hay. Late in the summer, just before plants start to dry out for winter, pikas make frenzied trips into alpine meadows, returning with mouthfuls of herbs. They cache the plants at the edge of a talus (scree) field near the alpine meadow interface, placing them out to dry under rocks where they are sheltered from most of the rain and snow. Since pikas do not hibernate, they can scurry around under the snow to visit their caches for food as needed. Mountain skiers often hear alarm calls as they approach a pika's precious food cache.

Pocket gophers *Thomomys talpoides* and Alpine mice *Peromyscus maniculatus* also hoard food. The caches of mice

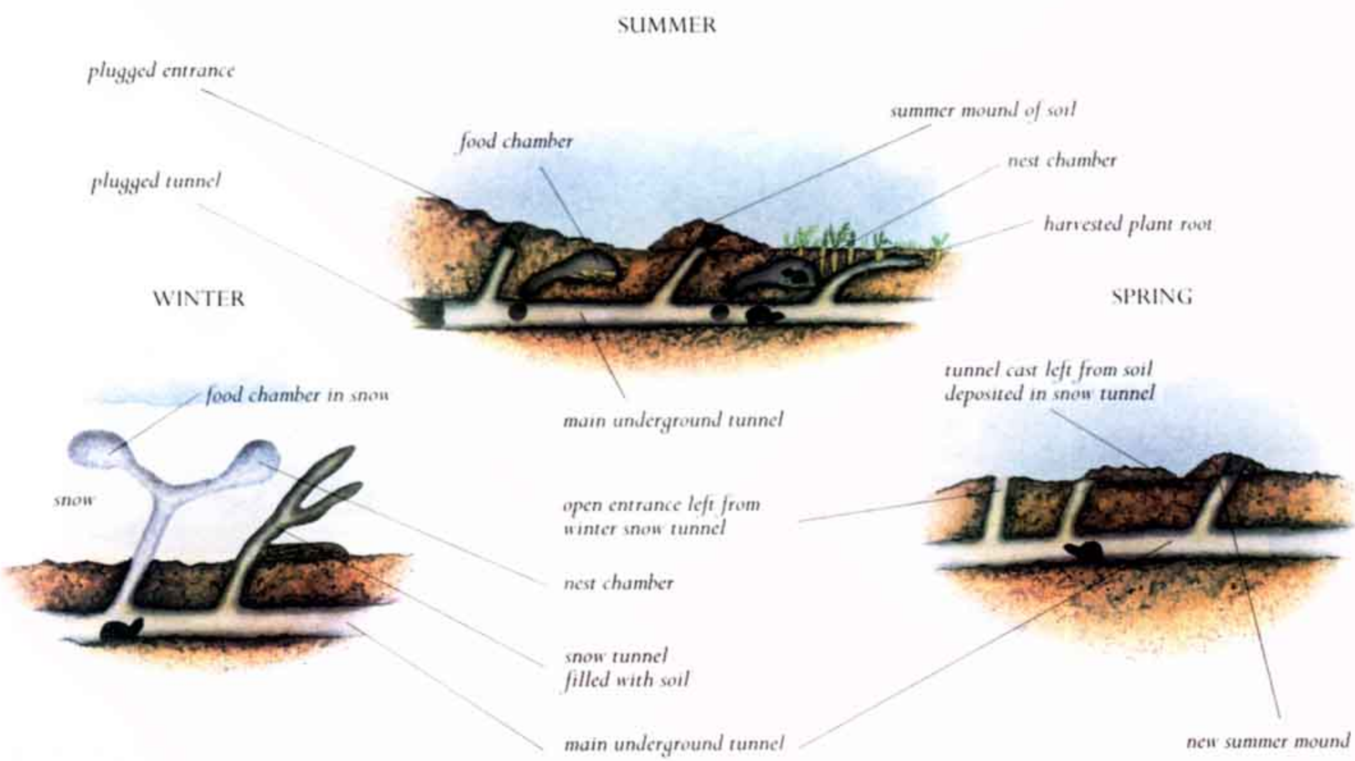
A HOME FOR ALL SEASONS



"FURRY EARTHWORMS"

Cold, wet soils prevent the survival of earthworms in high mountains. However, several families of mammals have adopted a burrowing way of life and act as "furry earthworms" of the mountains, turning over and aerating mountain soils. These species, including the pocket gophers of North America, mole rats of East Africa, mole-voles of the Caucasus Mountains, and zokors of China, tend to resemble each other, all having small eyes and ears, short, powerful legs, and long, sensitive whiskers. The northern pocket gophers are discussed in more detail here.

A HOME FOR ALL SEASONS



Built to tunnel and gnaw, the pocket gopher inhabits a range of habitats in western North America.

These subterranean dynamos of energy move massive amounts of soil. The northern pocket gopher *Thomomys talpoides* weighs approximately 100 grams (3½ ounces), yet it is able to move 50 kilograms (110 pounds) of soil in a 24-hour period. The gopher's inhabit deep galleries which are as much as 3 meters (10 feet) below the surface. They feed on roots and must constantly extend their tunnels to find new food sources. In the summer the soil is pushed to the surface to form a cone-shaped mound. The last earth is used to block the entrance, keeping the gopher safe from predators and protected from heavy rainfall.

Since gophers live at altitudes up to 4,350 meters (14,250 feet), deep snow covers their burrows in the winter. Not being a hibernator, the gopher continues to search for food along newly dug tunnels. When it needs a place to rid itself of the dirt, it burrows up into the hard, wind-packed snow and takes the excavated dirt into the snow tunnel. Each spring, as the snow melts, earth casts of snow tunnels are laid down on the ground, over rocks or bushes, or whatever was below the tunnel during the winter.

Not only do these furry earthworms keep the soil porous and friable, they enrich it by burying vegetation such as dried grass. Their tunnels also capture meltwater, which from there sinks deep into the ground. ●

may contain large amounts of seeds, while melon-sized caches of dried roots mark the activity of the gopher.

Voles of *Microtus* species construct spherical grass homes under the snow but do not hoard food. They simply move in tunnels beneath the snow to graze on grass and browse on willow twigs as needed. However, when wet winter weather causes ice to form in the snowpack, it prevents tunneling, and the voles often starve to death. Food hoarders seldom suffer this fate because their caches are large enough to last until spring warming.

Marmots (*Marmota* species) hoard food in another manner. As fall approaches, they too scurry about grazing, but for the marmot it is time to put on a thick layer of fat. As late summer rolls around, the marmots slip deep into their burrows to hibernate until spring. If they have a sufficient layer of fat, they will emerge in good shape for breeding in the spring. But if spring is late, or if the grazing the previous fall was inadequate, they too may die of starvation or hypothermia.

The Limits of Survival

High in the mountains, where conditions become so extreme that flowering plants can no longer live there, animals still survive. The land above the limit of flowering plants is known as the eolian zone. Without plants to produce food, many animals, including insects, spiders, lizards, snakes, and mice, survive in the eolian zone by depending on wind-blown nutrients from pollen, spores, seeds, dead insects, and plant fragments.

Here in the eolian zone there are three phases: the nival, the aquatic, and the terrestrial. In the nival or snow phase, wind-blown pollen and plant fragments are concentrated by adhering to the snow. When the snow melts and forms pools of water, fungi and bacteria grow on the decomposing products and various insects then feed on these materials. Eolian insects blown onto the snow are fed upon by wolf spiders, daddy-long-legs, and many birds such as the ptarmigan, water pipits, horned larks, and rosy finches. In the aquatic phase, glacial pools, meltwater runoff channels, and ponds support green algae that subsist on wind-deposited nitrogen-containing compounds. In turn, water fleas and insects live on the algae. Fairy shrimp live on glacial dust and organic debris. In the terrestrial phase, mites, springtails, and flies feeding on wind-blown debris exist without plants and are in turn fed upon by spiders of

Eric Dragesco/AUSCAPE

Alert for danger, an alpine marmot Marmota marmota *scans its surroundings in the Alps of Europe. Several marmot species inhabit mountains across Eurasia and North America.*

Left. *An inhabitant of the Rocky Mountains, the white-tailed ptarmigan* Lagopus leucurus *has close relatives in the high Arctic.*

Jean-Paul Ferrero/AUSCAPE

Tents of a communal Cyrtophora *spider in the southern highlands of Papua New Guinea. What appears to be a single web is in fact a multitude of tiny orbs spun by individual spiders. The "tent" often spans about 10 meters (33 feet) and is a deadly trap for insects flying through the forest canopy.*

Euophrys species, to altitudes as high as 6,700 meters (22,000 feet). Salamanders *Pseudoeurycea gadovii* thought to feed on eolian insects have been collected at altitudes as high as 5,000 meters (16,400 feet).

The alpine and, in particular, the eolian zones are good places to be a detrivitore (scavenger on dead material) or a carnivore (flesh eater) preying on the detrivitores. Herbivores (plant eaters) dwindle in numbers as altitude increases, and diminish dramatically at the beginning of the eolian zone.

INSECT MIGRATION

Lowland insects reach high mountains by two processes: migration and wind-blown influxes. Many species regularly migrate to mountains, some to escape lowland summer temperatures, some to feed as they grow to sexual maturity, and some to hibernate deep in rock crevices. Migratory insects provide a surprising source of food for the impressively large grizzly bear *Ursus arctos*. Some bears have been known to come directly from hibernation to high talus fields to feed almost exclusively on moths until it is time to hibernate again.

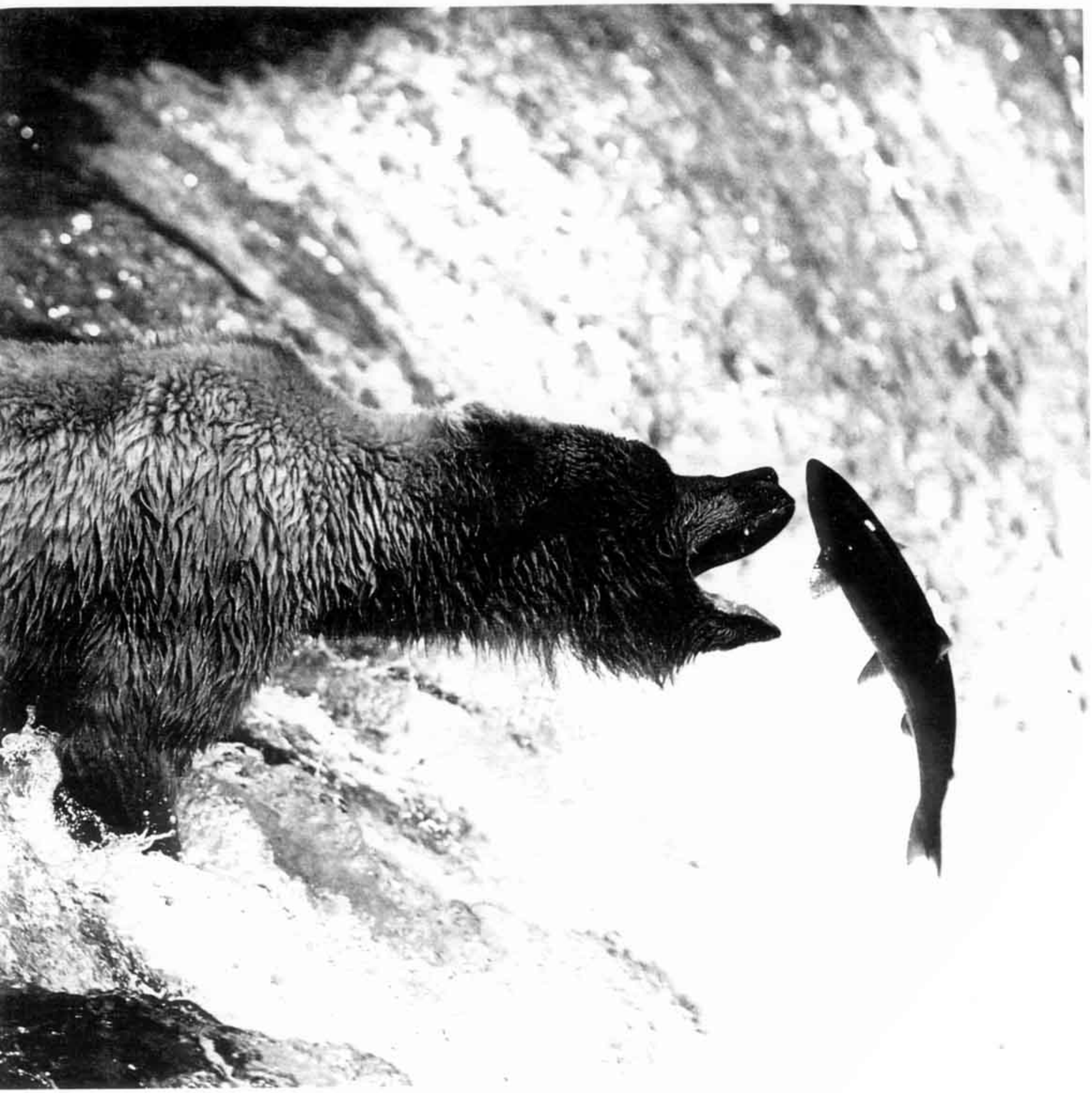
WIND-BORNE INSECTS

Large swarms of a single insect species are often blown into mountainsides by summer winds. When these lowland insects encounter the cold air, they tend to fold their wings and fall to the ground or snowpack. Dense concentrations have been reported on snowfields in North America, Mexico, Africa, and the Himalaya. These insects are often incorporated into layers within glaciers, such as in the "grasshopper glaciers" of North America. Preserved grasshopper carcasses may last hundreds of years deep in the ice before reappearing at the tongue of the glacier.

Besides natural nutrients, eolian insects may carry chemical compounds of human origin. Swarms of alfalfa moths *Loxostage cerareolis* blown from the Great

The Pacific giant salamander Dicamptodon ensatus *of the mountains of western North America.*

Galen Rowell/Mountain Light



Plains to the Front Range of Colorado were found to carry significant amounts of phosphorus derived from crop fertilizers. Before the insecticide DDT was banned in the USA, chemical analysis of ptarmigan eggs and chicks conducted in the same area identified insects as carriers in the transport of DDT from the plains to the alpine regions. Ptarmigan feed their young on the insects (whilst maintaining a vegetarian diet themselves), and the DDT became concentrated in their bodies.

Biological Timing

In a stressful environment, correct timing of biological activities is absolutely critical. Three timing rhythms are crucial to survival in the mountains: the day, the snow-free season, and the year. In the high mountains the warmth of sunlight and the cold of night occur every 24 hours. Carnivorous insects and spiders take advantage of these daily cooling cycles.

When salmon return from the sea to penetrate far up mountain streams to spawn, grizzly bears Ursus arctos *congregate from far around to take advantage of the temporary feast. Katmai National Park, Alaska.*

KINGS OF THE MOUNTAIN THRONE

Several fleet-footed hoofed mammals, such as the chamois, ibex, mountain goat, and tahr display an affinity with high rocky mountains. But the highest mountains, with the thinnest air, the coldest climates, and the hardest-to-reach places, are the domain of perhaps the greatest animal symbol of mountains, the mountain sheep.

Dall's sheep Ovis dalli *inhabits remote mountains in Alaska and northwestern Canada.*

Sheep have remarkable eyesight and are excellent climbers. Proud and confident, they stand atop the summits distrustful of all but their own kind. This aloofness protects them from predators and hunters. When spooked, a ram will bound gracefully down steep rock slopes, to disappear up unbelievably steep cliffs on the far side of the valley.

Genetic relationships within this group are not yet well understood, but scientists generally list seven wild species: the mouflons *Ovis orientalis* and *O. musimon*, the urial *O. vignei*, the argali *O. ammon*, and three bighorns—snow sheep *O. nivicola*, Dall's sheep *O. dalli*, and North American bighorns *O. canadensis*. The shape of their distribution pattern, what has been called by naturalist James Clark the "great arc of wild sheep", embraces both sides of the Pacific Ocean and on a map resembles the curl of a ram's horn.

David A. Ponton/Planet Earth Pictures

Dall's sheep, yearling lambs, Denali National Park, Alaska. Ewes bear one, occasionally two, youngsters in late spring, after six months' gestation. Right. *A North American bighorn sheep. In males, the horns may represent as much as 11 percent of the animal's total weight. Females have smaller horns.*

Argalis, with their huge spreading horns (as much as 183 centimeters/6 feet on each side), were reported by Marco Polo in 1273 and have been a legend of the mountains since then. Argali rams may weigh as much as 205 kilograms (450 pounds), and they have massive shoulders to support bone-jarring jousts with male competitors. In contrast, ram mouflons weigh a mere 32 kilograms (70 pounds).

Snow sheep and Dall's sheep have white fleeces, probably a necessity in their northern mountain habitat, while their close relative, the stone or black sheep *O. dalli stonei*, sports a blue-black coat.

Argalis, along with bharals or blue sheep *Pseudois nayaur*, are unfortunately disappearing from the Tibetan–Qinghai Plateau. The local herders carry rifles and shoot the wild sheep when they encounter them. Where sheep compete for resources with humans, the animals are losing. ●

Most insects lack the biochemical enzymes necessary to function at extremely low temperatures, so when night falls they climb into a sheltered spot to become inactive until the sun's rays again warm their environment. However, insect predators, such as spiders, centipedes, and other insects, have evolved enzymes that work at lower temperatures and allow them to be mobile at below freezing temperatures. They are able to walk among the rocks or on the snow surface in search of their prey, which is too cold to escape.

Reproduction in the mountains must be carefully timed to the snow-free season. Animals whose breeding cycle takes longer than the snow-free season simply aren't found in mountains. The water pipit *Anthus spinoletta* is an insectivorous bird that has evolved to raise its young quickly. By mid-May each year, flocks are returning from their southern wintering grounds to the North American tundra, and by June the males start to sing to attract mates. Females begin to lay eggs in late June; the eggs begin to hatch about two weeks later. The young mature quickly, gaining about 9 percent of their fledgling weight each day, to fledge in 12 to 13 days. By mid-August the juveniles are forming flocks that will join the adults for the migration south. From arrival to departure it is just over three months. However, if snowmelt is late, or if snowstorms occur in late spring or early fall, there is not enough time for the young to become large enough to fly south. If a late snowstorm destroys the nests, the pipits will re-nest, but late-born young are small, and mortality is high during the southern migration.

Widespread in northern forests and mountains, the common weasel Mustela nivalis *remains active throughout winter. It molts twice a year, so that it is brown in summer and white in winter, with a patchy piebald appearance midway through each molt.*

Yearly changes from the snow to the snow-free season demand careful timing for those species that are brown in the summer and white in the winter. Ptarmigan (*Lagopus* species) and weasels (*Mustela* species) turn white each fall for camouflage while snow is on the ground. The timing of the molt is controlled by biological clocks that respond to internal and external cues. Shortening day-length signals that the season has arrived to change color, and physiological preparations begin. Lowered temperature and the arrival of snow signal the final change to white. The process reverses in spring. However, if the timing is out, a brown ptarmigan on snow is easy prey for a predator, and brown weasels on snow have a hard time sneaking up on their prey.

Four relatives of the camel inhabit South America. These llamas graze alpine grasslands at 2,000 to 4,000 meters (7,500 to 13,000 feet). Vicunas and alpacas range even higher, while their lowland cousins, the guanacos, range down to sea level.

Opposite. *Most of the high mountain ranges of the world have their own distinctive member of the goat tribe, and some have two. In the Alps of Europe the local representative is the chamois* Rupicapra rupicapra.

Mysteries of the Mountains

Although all the world's mountain ranges have been explored, and many of the very highest peaks climbed, animal mysteries still exist in the high mountains. On each continent reports of large, unknown primates continue to be made. In China these creatures are called hairy men; in the Himalaya, yeti; in North America, big foot or sasquatch; and in South America, *mondo grande*. Lest we become too complacent about the possible existence of a large undisçovered primate, let us remember that the mountain gorilla *Gorilla gorilla beringei* of Africa was not discovered until the beginning of this century, and a previously undiscovered population of the lowland gorilla subspecies was found in West Africa in 1990.

Another elusive mountain inhabitant is the snow leopard *Panthera uncia*. An animal surrounded by myth and mystery wherever it occurs, the snow leopard inhabits the high mountains of central Asia. Low in numbers and patchy in distribution, most of its life is spent far above the timberline in the realm of its main prey, the bharal or blue sheep *Pseudois nayaur*.

Perhaps the high, forested regions of the world's mountains yet harbor an unverified primate that occasionally wanders above the treeline or crosses the snows to the other side of the mountain. Certainly, little is known about the small animals of the eolian zone, and much remains to be learned about ecological processes in the mountains. ■

Shadow of the snows, the endangered snow leopard Panthera uncia *inhabits the high country of central Asia.*

Manfred Danegger/JACANA·AUSCAPE

Notes on Contributors

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Dr. Allan is Associate Professor at the University of California, Davis. His interest in people of the mountains began at the age of 14 when he was a full-time shepherd in the highlands of Scotland. He did his PhD in cultural geography at Syracuse University, New York. The focus of 25 years of research has been mountain societies and habitats, especially in Afghanistan, Tajikistan, Tibet (China) and Xinjiang, Pakistan, Nepal, Bhutan, and India, with publications on pastoralism, mountain farming systems, ethnicity, impact on mountains of tourists and road transportation, mountain dwellers' diet and longevity, parks and conservation.

ROGER G. BARRY

Educated in England and Canada, Roger Barry has been Professor of Geography at the University of Colorado, Boulder, since 1971. He is a Fellow of the Cooperative Institute of Research in Environmental Sciences and Associate Director for the Cryospheric and Polar Processes Division. He has also served as Director of the World Data Center-A for Glaciology since 1977 and is Secretary of the International Mountain Society. He has published widely on polar and mountain climate, synoptic climatology, and cryospheric processes. Dr. Barry is the author of *Mountain Weather and Climate* (1981, recently published in a revised edition by Routledge) and was co-author of the widely acclaimed text *Atmosphere, Weather and Climate* (1968, now in press in a sixth edition), *Synoptic Climatology: Methods and Applications* (1973), and co-editor of *Arctic and Alpine Environments* (1974).

CYNTHIA M. BEALL

Dr. Cynthia Beall is Professor of Anthropology at Case Western Reserve University, Cleveland, Ohio. She is a physical anthropologist with special interests in the biological adaptation of human populations to high-altitude and mountainous ecosystems and in age differences throughout the life cycle in adaptation to the environment. She has conducted field research in Latin America (Peru and Bolivia) and Inner Asia (Nepal, Tibet, and Mongolia). Her current research projects are on the human biology of Tibetan and Mongolian pastoral nomads.

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Colin Burrows, PhD, DSc, is Reader in Plant Science at the University of Canterbury in Christchurch, New Zealand. His research interests are paleoecology, forest, wetland and alpine ecology, vegetation dynamics, and seed biology. He was appointed lecturer in ecology in 1960 and has lectured on biology and human concerns since 1975. Travel and study in Britain and the mountains of Western Europe, Scandinavia, the United States (Rocky Mountains), New Guinea, and Australia have resulted in many research papers and the book *Processes of Vegetation Change* (1990). He is actively involved with many conservation issues in New Zealand and elsewhere.

DAVID J. FOX

David Fox is Senior Lecturer in the School of Geography, University of Manchester, and has had an academic interest in mining for 30 years. This interest began during a year spent at a mining camp in northern Canada while attached to McGill University's Subarctic Research Laboratory. He has written some 50 articles on various aspects of mining, including the contribution of mining to development. His particular interests are tin mining and Latin American mining economies, and he is a regular contributor to the *Mining Annual Review* and *The Economist Intelligence Unit*. He is an authority on the Bolivian mining industry and knows at first hand the difficulties that mountains make for miners and the demands mining makes upon a mountainous environment.

ERWIN F. GROETZBACH

Dr. Groetzbach is Professor of Cultural Geography at the Catholic University of Eichstaett in Germany. He studied geography and economics at Munich University and has held professional posts at Erlangen University, Hannover University, and Eichstaett since 1980. His research on the human geography of mountains and the geography of tourism has involved many treks through the Afghan Hindukush, the Himalaya, the Karakoram, the Black Sea Mountains in Turkey, the Rocky Mountains, the Pyrenees, and the Caucasus.

JAMES C. HALFPENNY

Dr. James Halfpenny is past Field Director of the Mountain Research Station, the alpine branch of the University of Colorado's Institute of Arctic and Alpine Research (INSTAAR), and has led expeditions and conducted research in the tundra regions of the United States, Canada, Greenland, Kenya, and Antarctica. He is currently Research Affiliate, with INSTAAR, and Director of A Naturalist's World, in Gardiner, Montana. Two recent research projects include the first Sino-American survey of endangered mammals on the Tibet-Qinghai Plateau of China, and the Tanzanian Mammal and Dinosaur Tracking project. Since 1961 Jim Halfpenny has taught ecology and outdoor education programs for many universities, schools, and state and federal agencies. Each year he conducts field programs called 'Tracking the Great Bears of North America' and 'Dance with Wolves'. He is the author of *A Field Guide to Mammal Tracking* and *Winter: An Ecological Handbook*. He is a fellow of the Explorer's Club and listed in *Who's Who in the World*.

KENNETH J. HSÜ

Dr. Hsü has been a Professor at Eidgenössische Technische Hochschule (ETH), Zurich, Switzerland since 1974. On graduating from Nanjing University he studied at Ohio State University and did his doctorate at the University of California, Los Angeles. In 1970, 1975, and 1980 he was Co-Chief Scientist on deep-sea drilling expeditions and in 1979 was consultant to the Ministry of Geology, People's Republic of China. An active member of international scientific organizations, he has served the International Association of Sedimentologists as editor-in-chief of the bulletin *Sedimentology* 1971–79 and President 1978–82, and chaired several International Union of Geological Sciences (IUGS) Committees, including the IUGS Commission on Marine Geology in 1980–89. Visiting fellowships and lectureships have included US National Academy of Sciences exchange fellow to Eastern Europe (Bulgaria, Romania, Poland, Yugoslavia), and Walter Ames Professor, University of Washington, Seattle, in 1989. He has been honored as Wollaston Medallist by the Geological Society of London; Foreign Associate of the US Academy of Sciences; honorary doctorate, Nanjing University; and member of the Chinese Academy of Sciences, Taipei.

JACK D. IVES

Graduate of the University of Nottingham (UK) and McGill University, Dr. Ives is currently Professor and Chairperson of the Department of Geography, University of California, Davis, Coordinator of the United Nations University Project of Mountain Ecology and Sustainable Development, President of the International Mountain Society, and Editor of the quarterly journal *Mountain Research and Development*. His areas of specialization are mountain and Arctic physical geography and mountain resource use, and conservation and development, especially in the Himalaya, Alps, Rocky Mountains, and Arctic regions. During student and early post-doctoral years he led a series of expeditions to Arctic Norway, Iceland, Labrador, and Baffin Island, studying glaciology, permafrost, geomorphology, and the history of the last ice age. He was appointed Director of the Institute of Arctic and Alpine Research, University of Colorado, Boulder (1967–79), and Professor of Geography (1967–89). He was also founding editor of the quarterly journal *Arctic and Alpine Research*. This led to alpine tundra research (International Biological Program—IBP) in the Colorado Front Range and a series of interdisciplinary mountain projects, such as avalanche research, study of ecological impacts of winter cloud seeding, and the establishment of wilderness areas and biosphere reserves. In 1976–77 he was Guggenheim Fellow and Visiting Professor at the University of Berne, Switzerland. After 1978 his research emphasis shifted to applied studies in the Himalaya, Tibet, southwest China, and the Andes through the United Nations University (UNU). This is now being extended to include the Soviet Pamirs and Altai. He has contributed to the world mountains status report for United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, in June 1992. This was a team project funded by the government of Switzerland, and UNU designated Dr. Ives as one of the two delegates to present the ensuing recommendations. Dr. Ives was the co-editor with Roger Barry of *Arctic and Alpine Environmnents* (1974) and co-editor with Bruno Messerli of *The Himalayan Dilemma: Reconciling development and conservation* (1989).