Is There Life After Climate Change?

Yes, but the world will be a different place, with an abundance of male alligators, migrating trees, and a plethora of parasites

HOW WILL THE EARTH'S BIOTA respond to the predicted greenhouse warming? If the climate models are correct, within 50 or 100 years the earth will be hotter than it has been in the past 1 million years. Will plants and animals be able to adjust, either physiologically or behaviorally, to the altered regime? Will they have time to migrate to cooler climes? Or will they perish?

That was the topic of a meeting in early October at the National Zoo in Washington, D.C., sponsored by the World Wildlife Fund and attended by nearly 400 scientists, conservationists, and a handful of government officials.*

The view that emerged was bleak. Biological communities will be disrupted, ranges will shift, and some species will go extinct, though it is hard to say exactly what or where. Globally, biological diversity will diminish.

In broad strokes, the warming will be greatest at higher latitudes, which spells trouble for the Arctic tundra and the numerous species, like migratory birds, that depend on it. Coastal organisms will be especially hard hit by rising sea levels and salt water intrusion. In the Northern Hemisphere, forests and other ecosystems will shift northward, and some species at the southern limits of their ranges will die off. Those species now confined to nature reserves—by and large endangered species that nations have labored to protect—will be especially vulnerable as suitable climate and habitat shift out of the reserve borders.

Some plants will undoubtedly do better and in some areas agriculture may benefit, but, as Boyd Strain of Duke University cautioned, "you cannot benefit one species in a closed system without detriment to another."

But it was not those general trends, which have been outlined before, that set this meeting apart. Rather it was the details, speculative as they may be, of what might happen to specific organisms, or plant-animal interactions, or ecosystems, that provided the most intriguing glimpses into the world to come.

The assembled experts foresee, among other things, skews in the sex ratio of alligators and turtles, havoc with the social communication of insects, changes in elephant's social behavior and ultimately reproductive success, extinction of beech and other trees across much of the United States, a far weedier world overall, and a heyday for parasites and pathogens, which could mean an influx of tropical diseases into the temperate zone.

All of this is doubly speculative, as the speakers were the first to admit. They started with general circulation climate models, which are uncertain in their own right, and then extrapolated from them to the biological response, gamely using whatever data were at hand: the fossil record, theoretical models, physiologic data on temperature stress, and the like. Invariably, much of discussion veered out on the limb of "data-free speculation," as Peter Myers of the Nature Conservancy called it.

But however tenuous the details are, there was clear agreement that the biological changes will be extensive and that surprises are guaranteed. Noted Thompson Webb of Brown University: "We are moving into a new biological world."

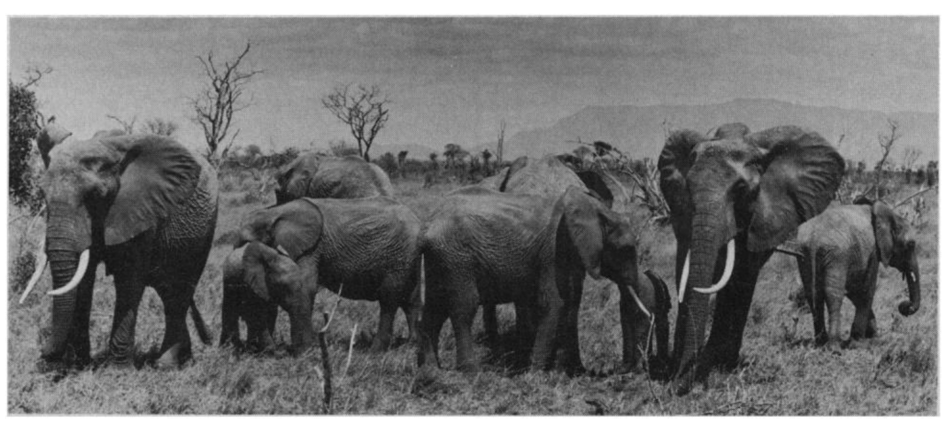
All of this is brought on by the dramatic climate changes expected to come. As Stephen Schneider of the National Center for Atmospheric Research noted, the greenhouse theory is one of the least controversial in atmospheric science: the problem is in the details. The increase in greenhouse gases, principally carbon dioxide, will bring an average warming of, say, 2° to 5°C over the next 50 or 100 years. Regionally, the temperature could rise 10° or drop 3°, but the models are shaky on where.

Uncertainties notwithstanding, the models are pretty credible on the magnitude and rate of change, said Schneider: "The rates are very, very fast, and it is the speed that scares me."

Organisms and ecosystems have faced climate swings like this before, but what is different now is both the rate of change—it is predicted to be some 10 to 40 times faster than the average rate of warming following the last ice age—and the fact that it is occurring in a "man-dominated" landscape, as conference organizer Robert Peters of the World Wildlife Fund has called it. During past warmings, plants and animals responded by migrating northward to more hospitable climates. But today, habitats are fragmented, and many species are "man-locked": even if they could keep pace with the unprecedented rate of climate change, their routes might be blocked by cities, roads, agricultural lands, and the like.

It is not just temperature alone that is of concern. Rainfall is expected to increase globally, but again, not everywhere. Evaporation rates will probably increase, circulation patterns will change, as may soil and water chemistry. Some researchers predict an increase in severe storms and forest fires.

Atmospheric carbon dioxide levels will climb to a level where they have not been in at least 1 million years. "We are moving from a carbon-starved to a carbon-fertilized world," said Strain. "We don't know what the effect will be on the carbon balance between the biosphere and the atmosphere. True, the world has seen high carbon dioxide levels before, but that ended 1 million years ago. All Pleistocene evolution occurred in a car-



Leonard Lee Rue III/Animals Animals

African elephants. *The dominant bull may lose his monopoly on copulation.*

* "Consequences of the Greenhouse Effect for Biological Diversity," 4 to 6 October 1988.

bon-limited world."

Some clues as to what these physical changes might mean for the biological world can be gleaned from the fossil record, which shows a far more complex response to climate change than generally predicted.

At the end of the Pleistocene, some 14,000 to 10,000 years ago, the earth warmed up perhaps 3° to 5°C. Although this temperature hike is similar to that predicted for the greenhouse effect, it was spread over a few thousand years, not compressed into 50 or so.

The lesson from the earlier warming, said Russell W. Graham of the Illinois State Museum, is that climate change will not bring a simple northward shifting of ecosystems, with the entire boreal forest and all of its inhabitants moving up into the tundra, as generally described. Rather, it will bring a complete reorganization of biological communities.

When the climate began to warm some 14,000 years ago, said Graham, the biological communities of the ice age were literally pulled apart. And each species—plants and animals alike—responded differently, according to its own tolerance, going its own direction, at its own pace, yielding entirely new communities.

The upshot, said Graham, is that while it is guaranteed that biological communities will be different after climate change, it is folly to try to speculate on what those communities will look like.

To Margaret Davis of the University of Minnesota fell the task of figuring out what will happen to four important North American trees under greenhouse conditions: yellow birch, sugar maple, hemlock, and beech. She predicted a tremendous displacement of ranges for all four species, from 500 to 1000 kilometers to the north, by the time atmospheric carbon dioxide has doubled from preindustrial levels, the benchmark in calculating greenhouse effects. All four species will go extinct along the southern limits of their current range.

Beech shows the largest range shift. It would go extinct throughout southeastern United States, except perhaps at high elevations, and its habitat would be limited to the northern Great Lakes, with new potential habitat opening up 500 to 1000 kilometers north in Ontario and Quebec.

Whether the species can get there is another matter, as is the question of whether it will even survive at the northern bounds of its current range. The fastest known dispersal rate is for spruce, which migrated an average of 200 kilometers a century about 9000 years ago. For beech, the rate is about 20 kilometers a century. "That is pretty good for a tree," said Davis, "but it won't be fast enough if they have to disperse 500 kilometers in the next century."

© Grant Heilman

Sex skews. *A preponderance of male alligators following climate change?*

Again, the rate of warming is key. If carbon dioxide doubles in 100 years, said Davis, then these four species will not make it to their new habitat without human intervention.

To date many in the field have taken comfort in the notion that while trees may go extinct in the southern United States, at least those already growing in the north will survive. But, according to Davis, this is not necessarily so. It all depends on whether the northern ecotypes will be able to adapt to a warmer climate—say, whether beech growing in Maine will survive when the climate rapidly changes to one resembling Georgia, as it is predicted to do within the lifetime of one tree.

It is not known whether the specific adaptations of a Maine beech tree—to day length and summer temperature, for example—reflect a plastic response to the local conditions, which means the tree could adapt to new conditions as well, or whether they are hard-wired into the trees genetically. If the adaptation is genetic, Davis warned, the problem could be far worse than anyone has imagined. It may, in fact, be necessary to transplant southern ecotypes to the north if the species is to survive.

Another big unknown for vegetation is the direct effects of carbon dioxide, which acts as a fertilizer. A few things can be said with certainty, according to Boyd Strain: net photosynthesis will go up, and water loss through leaves will decrease.

However, all plant species respond differentially to any environmental change, carbon fertilization included, said Strain. And though most plants will benefit, some will benefit more than others, thereby outcompeting and perhaps eliminating species with a lesser response. "Unfortunately," said Strain, "carbon dioxide fertilization favors weedy plants. So the world will become weedier."

And what happens to vegetation will play out to the insects and animals that feed on it, said David Lincoln of the University of South Carolina, who looked at plant-herbivore interactions. Take the banana slug and the native mint that it feeds on in moist redwood forests. The slug is constrained to a habitat of high humidity. Thus, as the microclimate becomes warmer and drier, the benefit would fall to the plant, as the slug is increasingly restricted to the dwindling humid habitat.

For the butterfly and the sticky monkey flower, the opposite holds true. The butterfly requires high irradiation, and the plant escapes herbivores by penetrating into a shady, cooler habitat. In this case, an increase in temperature would tend to favor the butterfly.

And then the direct effects of carbon dioxide fertilization must be factored into the equation. Many plants accumulate more carbohydrates when fertilized with carbon dioxide, said Lincoln. As a result, the protein content of the leaf declines.

Insect herbivores, like the soybean looper, compensate for this lower nutritional value of the leaves by eating more. Thus, while carbon dioxide fertilization will increase plant growth, feeding by insect herbivores, at least, will also go up.

For animals, Daniel Rubenstein of Princeton University foresees myriad changes in behavior, reproductive strategy, and overall life history stemming from the greenhouse.

Changes in temperature and moisture will not necessarily affect a species the same way in all parts of its range, said Rubenstein. At the northern edge, changes in temperature can be beneficial, allowing organisms to expand their range and increase fitness. But at the southern edge of a range, where species are barely coping as is, changes are likely to be disruptive.

Locusts, aphids, and moths become more active and more fecund as temperature or humidity rises, which has sobering implications for agriculture. Moreover, added Rubenstein, if the pests have the genetic potential, higher temperatures might allow them to complete two life cycles in one crop growing season, "meaning some crops will get hammered twice."

Sex ratios among reptiles may become distorted. At high temperatures, lizards and alligators produce mostly males, while turtles produce mostly females. "We could end up with a total absence of one sex, or incredible skews in the sex ratio," noted Rubenstein.

The indirect effects of climate change are harder to get a handle on but may be just as powerful. Changes in temperature and wind could disrupt communication among social insects that depend on pheromones.

Changes in habitat, whatever form they take, will alter the social structure of animals, said Rubenstein. And changes in social structure, in turn, can have pronounced consequences for behavior and genetics.

For example, during the rainy season when vegetation is ample, female elephants tend to aggregate on the plains in large herds, allowing one bull to dominate and sire many offspring. Younger, lower ranking bulls usually copulate in the dry weather, when the females break into smaller groups and return to the swamps. If the greenhouse brings drier weather and the elephant population is fragmented, then the dominant bull may lose his monopoly on copulation, bringing greater variety, and perhaps inferior traits, to the gene pool.

One thing seems all too clear: changing climate will spell boom days for parasites and pathogens, predicted Andrew Dobson of the University of Rochester. "Parasites are good at solving problems, and because they reproduce so quickly, they always win."

Haemonchus contortus, a nematode that causes an economically important disease in sheep, should do quite well under greenhouse conditions, said Dobson. Although the worm's survival time decreases at higher temperatures, its development time rapidly increases; thus, it remains infective over a wide temperature span. As a result, the pathogen may be able to increase its range at a time when resistance to drugs is spreading.

For the tsetse fly, which carries the trypanosomiasis that causes sleeping sickness, things may take an unexpected turn. If the temperature rises 2°C, as one of the climate models predicts, the tsetse fly might disappear from the middle belt of Africa, where it is now endemic, and move further south. From a conservation perspective, that could be devastating in that the presence of sleeping sickness keeps out humans and their domesticated animals. As the tsetse fly moves south, much of the land that is now a de facto wildlife reserve would be open for human exploitation.

The bottom line, said Dobson, is that some parasites and pathogens will do really well. Although some rare species may go extinct, "some now-obscure parasites will probably make a name for themselves." What it may mean, he warned, is that many of the infectious diseases that now occur only in the tropics, will, with increased warming, spread to the temperate zone.

What does all this mean for conservation? The overriding task, it was generally agreed, is to slow the rate of climate change. But even if all the greenhouse gases were somehow turned off tomorrow, a 1° to 2°C warming is already in the pipeline. And, Peters noted, temperature swings of 1°C or less have brought documented shifts in ranges.

Mitigation strategies might include setting up corridors between protected areas that will allow species to migrate, especially north-south corridors, and designing new reserves with climate change in mind, which might mean ensuring that they contain adequate water and a varied topography, as it is easier for a species to go up a mountain than to trek hundreds of kilometers north. More monitoring and more intensive management of wildlands seem certain.

"Those of us who are into 'the natural' are not going to like what we will have to do, which is damage control to minimize the amount of loss," added Jerry Franklin of the University of Washington. "We will have to become ecological engineers, managing natural areas."

It was Russell Graham, however, who called into question the premise on which much of conservation has been based. The fact that plants and animals respond individually to climate change, as the fossil record shows, rather than collectively as communities, raises fundamental questions about just what conservationists should try to protect: community patterns or biodiversity in general. Most conservation efforts to date have focused on the former, an approach Graham considers misguided.

"Communities are not static entities. They have been changing in the past and we can assume they will change in the future," said Graham. "The question is, can we accommodate change and allow new communities to form naturally, by providing migration corridors, or do we take a more controversial course and manufacture new communities ourselves?"

Graham is the first to admit that manufacturing new communities could cause all kinds of havoc. "I would prefer corridors to let things happen naturally, but if we can't do that, the alternative might be to transplant species. We hedge our bets if we distribute species over a broad area. Those species that are geographically confined are more likely to go extinct."

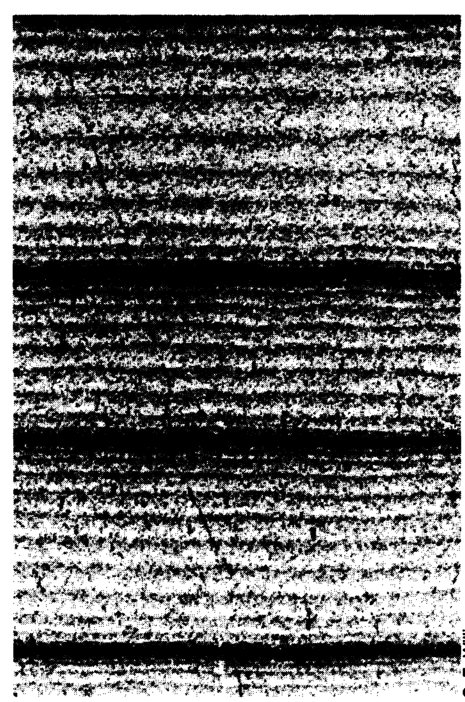
■ LESLIE ROBERTS

A Sun-Weather Connection Broken

It seemed too good to be true, and it was. Until last year, the most promising evidence of a link between varying solar activity and Earth's weather seemed to be recorded in 680-million-year-old sediments from Australia. The discoverer of this ancient sun-weather link, George Williams of the Broken Hill Proprietary Company Limited in Victoria and his subsequent collaborators, assumed that the thin laminations in the rock were annual sediment deposits whose rhythmically varying thicknesses reflect the ancient solar cycle.

Williams has changed his mind, in light of the discovery of additional laminated sediments at other Australian sites. He says the more reasonable interpretation now is that the rock recorded lunar tides rather than solar cycles.

The solar cycle interpretation seemed likely, if not inevitable, in 1980 when Williams first wrote up his results. Cycles containing about 11, 22, and 90 laminations were evident in the layered Precambrian rock, just as cycles containing the same number of



G. E. Williams

Now tidal signals.