EDITORS' SELECTION

DISEASE, PESTS, AND IMPACT ASSESSMENT

*Paul R. **Epstein,** M.D.*[1]

As currently performed, risk analyses of chemicals in the environment account only for direct effects: cancers, birth defects, premature births, etc. But chemicals like dioxin, PCBs, and pesticides may have even greater indirect affects on emerging infectious diseases. Through immune suppression and by mimicking hormones, these chemicals may affect bird and fish populations—and not merely as sentinels of future human impacts. Weakened bird populations may harbor an elevated burden of viruses (e.g., Eastern Equine, Western Equine, and St. Louis Encephalitides); and, with reduced numbers of inland fish (consumers of insect larvae), mosquito carriers may flourish (see box on next page). Morbilliviruses (canine distemper virus, rinderpest, and measles) have been fatal to aquatic and terrestrial mammals (seals, Australian horses, Serengeti lions), and an iridovirus may be involved in the disappearance of frogs from six continents. How do these evolving pandemics across a wide taxonomic range reflect alterations and evolution in agents, vulnerability of hosts, and changes in the environment?

---

[1] Paul R. Epstein, M.D., M.P.H., is with the Harvard School **of** Public Health, Working Group on Emerging Diseases. He **is** based at the Cambridge Hosptial/ Harvard Medical School, 1493 Cambridge St., Cambridge **MA** 02139 **USA** (pepstein@igc.org).

Recently dioxin was shown to activate HIV-1 gene expression through an oxidative stress pathway affecting cytochrome P450 CYP1A1 enzyme (Yao et al. 1995).

Dioxin apparently impacts DNA and DNA repair mechanisms, immune cells and reservoir organs, animals in the environment, and community assemblages of species. Dioxin increases mutations, damages 'proofreading' genes (e.g., p53) that correct mismatched base-pairs, and decreases T-cells through cell death (apoptosis) and damage to the thymus.

Similarly, immunological impacts on nonhumans (e.g.,birds, reptiles, fish) may affect their capacity to ward off opportunistic infections and influence their populations, thus altering predation on rodents and mosquitoes – pests and transporters of pathogens.

True impact assessment must include ecological effects, not merely for æsthetic reasons, but for the biological control of opportunistic pests and pathogens. Owls refuged in Northwest forests, for example, control rodent populations involved in Lyme disease and Hantavirus events that occur elsewhere. To fully assess impacts, obvious first-order results must be integrated with background changes. such as habitat loss that crowds bird populations thus amplifying contagion, and wide temperature fluctuations and altered timing of the seasons (climate instability) that disturb species' synchronies.

Assessing the impacts of change on pests and infectious disease patterns is important for measuring the full impacts of our actions on the set of interacting complex systems that make up the macrocosm. Factors regulating the selection and abundance of species and community composition include (1) nutrients (chemical),(2) meteorological conditions and habitat (physical), and (3) disease, competition, **and** predation (biological). A disturbance in one factor can be strengthening or destabilizing; multiple perturbations occurring at the same time may affect the resilience of the system and resistance to invasion or overgrowth of opportunistic species.

ECOLOGY, PESTS, AND DISEASE

On a cellular and organismic level, evolution and selection are dependant on environmental factors. Rejecting the ‘central dogma’ that all information flows from genes to proteins, Barbara McClintock helped us understand that genes are expressed and repressed, regulated and controlled by other genes; that they ‘jump’ (transposition) and, perhaps, even mutate more rapidly than random in response to environmental pressures, perturbations, and nutrient availabilities. Recent work (Beck 1995) has found that nutritional deficits in mice can ‘allow’ mutant, pathogenic strains of organisms to evolve, given a weakened immune surveillance system.

On a macro, phenotypic level, the pattern of a stand of trees or a colony of fire ants develops in relation to environmental constraints, competition, and nutrients. We now understand that ‘survival of the fittest’ includes how organisms and species fit and co-evolve into intricate ecological systems, not just that they fight amongst themselves with only the strongest surviving.

Competition and cooperation—symbiosis and mutualism—are necessary within nuclei, within cells, within organisms, and in ecological systems. Just as maintaining a healthy body requires a diversity of vigorous responses against microbiological intruders, so networks involving multiple species may be involved in controlling biologically the exponential growth of opportunistic species.

Weeds, rodents, insects, fungi, algae, protozoa, bacteria, and viruses are opportunistic species. While selective pressures are relative, given the particular assemblage in an area, the proliferation of ‘pioneer’ groups is often dominated by r-selection; i.e., they grow rapidly, are small in body size, and have huge broods and good dispersal mechanisms (thus high r, the intrinsic rate of increase). R-strategists are good colonizers of disturbed environments (and of weakened hosts) while species exhibiting K-selection (reflecting the carrying capacity of the environment) in a particular assemblage are larger, reproduce later in life, and are slower to develop, but are superior competitors in a stable environment. To be sure, such strategies are relative and the predator of one group may be prey of another. But predator–prey relationships (e.g., birds of prey, reptiles, and felines vs. rodents; fish vs. insect larvae)—and competition—may play a part, along with food supplies, in regulating the size of populations.

The Volterra predator-prey relationship (described by the Lotka-Volterra equation) is an ecological principle fundamental for understanding disease emergence and resurgence. When predator and prey are both reduced because of habitat fragmentation, pesticides, or climate extremes, the prey—more rapidly reproducing and evolving (resistance)—can rebound with punishing ferocity (as Rachel Carson eloquently depicted). Additionally, models of population dynamics of predators and prey that exclude refuges, camouflages, and migration from and to other systems are not sustainable. (Predator and prey are eliminated.) Habitat reserves are necessary, for example, to preserve large raptors (e.g., owls) that control rodent populations elsewhere. As 'specialists' dependant on localized niches, large predators may ultimately be more fragile than the more opportunistic prey. 'Generalists', with wide-ranging diets (some decomposers), may dominate over specialists in disturbed, fragmented, or polluted environments, and those undergoing accelerated climatic change.

DISEASE ACROSS TAXA

Many diseases of plants, birds, fish, and mammals are indicators of environmental ill-health as a result of direct effects of toxins or the indirect effects on species function and the selection of virulent strains.

Stresses and responses occur in biogeochemical and social/economic/political realms. while inputs (e.g., chemicals) or resource depletion have direct and indirect local impacts. Widespread perturbations (e.g., fossil fuel pollutants, deforestation) affect ecosystems, and when changes involve biotic feedbacks and occur on a global scale, they can affect the climate system. Periods of ecological and climate change may be associated with extinctions of some species and emergence of new ones.

Pests and pathogens may be among the first to emerge during some of these transition periods. An altered balance of species combined with stressful environment may provide selective advantage to pioneering, opportunistic, and toxin-producing organisms, contribuating to an initial redistribution of vectors and animal reservoirs of disease.

BIOLOGICAL INDICATORS

Insects, the most abundant and diverse group of animals, are especially sensitive biological indicators in terrestrial ecosystems—many are stenotherms (adapted to narrow thermal conditions) and have short generation times. While abundance and diversity may be controlled by biotic factors (landscape, predator–prey ratios, competition, and parasitism) at the center of a species' range, thresholds and optimum ranges in bioclimatic conditions (temperature and humidity) limit populations near the edges of their range. Abiotic factors affect breeding sites, maturation rates, intrinsic parasite incubation, and biting behavior. Thus the persistence of insect populations at new altitudes and latitudes provides a sensitive indicator of climatic change. And while climate limits the distribution of insect vector-borne diseases, weather determines the timing of outbreaks. Overall, the abundance and behavior of insects may rapidly integrate ecosystem health (diversity, productivity, vigor, invasibility, and resilience) and climate change.

Paleological records support a strong link between past climatic transitions and increases in insect fauna. Fossil assemblages from ecotones (the edges of ecosystems) demonstrate that insects responded rapidly to warming in North America and Europe during the last deglaciation (10,000 y.a.)—redistributing in years, while grasslands, shrubs, trees, and wildlife took hundreds of years to shift. The work of Russell Coope's group in Great Britain demonstrates that minimum temperatures (nighttime and winter TMINs) are best correlated with redistribution of assemblages of insects, and one can read temperature changes closely as they changed (based on Greenland ice cores and other paleothermometers) from the glacial maximum through the Younger Dryas to the Holocene. "Beetles are better climatic indicators than bears," wrote P.D. Moore in 1986 (***Nature*** 294:385).

Rodent populations in arid rural—and urban—settings are another group of rapid responders to environmental change (e.g., food supplies and wastes) and altered biodiversity (reduction in predators). With catholic diets and extensive networks of underground burrows, these small mammals can rapidly proliferate with food surges and declines (or lags) in natural enemies.

In coastal marine systems, algae may operate as key indicators of ecosystem function, integrating eutrophication, wetland acreage (nutrient filters), predation levels (of finfish, shellfish, and zooplankton), and sea surface temperatures. In fresh water (lacking dissolved carbonate) CO, fertilization adds further stimulus to phytoplankton growth. The increase in algal blooms and growing incidence of toxic phytoplankton species reported worldwide by planktonologists may reflect these widespread ecological and global changes, and represent adaptive responses to enhanced environmental stress and altered marine biodiversity. Indeed. "the worldwide increase in coastal algal blooms may be one of the first biological signs of global change" (T. Smayda, pers. comm.).

Moreover, insects and rodents are carriers of many plant and animal (including human) viral, bacterial, rickettsial, and parasitic diseases, and some are avid herbivores. Algae harbor *Vibrio cholerae* and other human enteric pathogens and suffocate coral and seagrass beds; harmful algal species manufacture biotoxins that affect finfish, shellfish, marine mammals, sea birds, and humans.

Combining the surveillance of biological indicators and relevant health outcomes (to include food security and nutrition) with ecological and meteorological data sets can (1) furnish essential links in an integrated assessment of climate and ecosystem change, (2) provide a basis for calculating the costs of climate change, (3) contribute to the detection of climate change ('fingerprints'), and (4) support a systems-based approach to the design of adaptive and preventive responses for environmental restoration (e.g., wetlands for waste management) and ecosystem sustenance.

BIOLOGICAL INDICATORS AND ENVIRONMENTAL MONITORING

Bioindicators have been used primarily to monitor environmental accumulations of chemicals. But biotic responses are also integrators of ecosystem vulnerability and stresses endured. Monitoring key species that respond rapidly to environmental change (e.g., insects, rodents—urban and rural—and algae) can facilitate impact monitoring, climate change detection and the design of adaptations, mitigations, and preventive interventions that improve generalized resistance (e.g., spiders to control the invasion of exotic species or parasitic wasps to control herbivores).

Some such efforts are currently in the planning or early implementation stage. but many currently lack health components. The principles of examining terrestrial, marine, and ice-covered systems may be local and regional. Long-term ecological research sites (LTERs, NSF-funded) and the 'Man in Biosphere' program (MAB, UN-funded) could incorporate standardized biological indicator species and health outcomes. The LTER in New Mexico, for example, is now collaborating with the Centers for Disease Control and Prevention (CDC) to monitor rodent ecology and hantaviruses. Internationally, LTERs and MAB programs could include rodent monitoring for abundance and diversity, arenaviruses (such as Lassa in Africa, and Machupo, Junin, Guaranito, and Sabia in Latin America), and plague bacteria (*Yersinia pestis)*.

Large marine ecosystem (LME) monitoring has been funded by the Global Environment Facility for the Gulf of Guinea. Proposals have been submitted for the Chinese Yellow Sea and the Black Sea, with the intention of extension to the world's 49 LMEs that may serve as components of a Global Ocean Observing System (GOOS). The relative value of the driving forces affecting each system (e.g., overfishing, pollution, habitat loss, and climate) will be evaluated in order to inform policies for mitigation and prevention. Monitoring plankton, bivalves and finfish for biotoxins and vibrios, and surveillance of coastal nations for shellfish poisoning and cholera, will form an integral part of these projects.

A network of regional centers with support from the World Climate Program (Global Climate Observing System or GCOS) is being planned to monitor worldwide meteorological data. Other programs are planned to monitor ecosystem integrity and biodiversity (the global terrestrial, ocean, and world hydrological observing systems or GTOS, GOOS, and WHYCOS). These will be augmented by remote sensing (NASA and others) and assimilated into geographic information systems. The global change system for analysis, research and training (START) program of the International Geosphere–Biosphere Program (IGBP), World Climate Research Program and Human Dimensions Program, will involve 13 regional research networks, numerous regional research centers, and affiliated sites. At the same time the CDC and the World Health Organization are planning an international consortium of regional centers for enhanced surveillance and response by clinical, laboratory, and epidemiological means to respond to the global emergence, resurgence, and redistribution of infectious diseases.

Monitoring by ecosystem involves a number of strategies, including ecosystem status monitoring (extent, distribution, and rates of loss [or gain]), fragmentation, and edge effects by remote sensing and fractal dimensions analysis of landscapes, carrying capacity (storage), intensity (processes and functions), and population-community (biodiversity) indices. Stresses and perturbations may be site-specific and generalized, and time series are needed to detect shifts and early warning signs. Analytical methods utilized are canonical, cluster, discriminant, and principal component.

For each region, primary, secondary, and tertiary driving forces of environmental change will differ. Among the principal forces of global change are extraction and exhaustion of nonrenewable resources (including fossil fuels and wildlife species), over-exploitation of renewable resources (forestry and fisheries), and the generation of wastes beyond the capacity of biogeochemical systems to recycle them. These forces are sometimes 'exported' to other regions, through the import of goods or export of aerosolized, liquid, and solid wastes. The driving forces are all influenced by population (growth, aggregation and migration), income gaps, economic and energy policies, technological, and behavioral changes, and political will.

CONCLUSIONS

To provide an integrated assessment of the human impacts of our interventions in the environment, information on health outcomes and biological indicators must be 'fused' with data sets on ecology and meteorology. Key biological indicators—insects, rodents, and algae—can provide important links between environmental monitoring and studies of human dimensions.

There are practical applications for future scientific inquiry, and for ecosystem management and for policies. Integration can be applied on local levels through coordination of programs monitoring environmental resources, weather conditions, agricultural yields, and health statistics. LTER and MAB sites, and LME programs provide the foundations. In the U.S. the Climate Analysis Center (NOAA) defines four regions for weather surveillance: Coordinating ecological (EPA and National Biological Survey), agricultural (USDA), and health data (CDC) through these centers could provide the basis for regional assessment and monitoring.

Internationally, multidisciplinary application centers are being developed for multiple sectors (agriculture, fisheries, health, energy (hydroelectric), and industry). Advances in climate forecasting can be useful in the development of health (as well as famine) early warning systems, providing advanced notice of bioclimatic conditions conducive for disease and pest outbreaks, permitting timely implementation of environmentally sound interventions (e.g., community education, Bti applications, water boiling, vaccination campaigns). These application centers (planned by NOAA and the IGBP) can ultimately form a network under the rubric of the world climate program and the global observing systems.

The fusion of systems and scientific work, drawing on remote sensing, and field and laboratory observations, that include key indicator species (their abundance, composition, and distribution) together with health outcomes (of fauna and flora), can constitute **an** efficient methodology for achieving **a** dynamic, integrated ecological risk assessment of anthropogenic activities that impact our ecosystems, our climate, and our health.

Acknowledgments
The author acknowledges the helpful input of ecologists Richard Levins (Department of Population Sciences, Harvard School of Public Health), Andrew Dobson (Department of Ecology and Evolutionary Biology, Princeton University), and John Vandermeer (Department of Biology, University of Michigan).

REFERENCES

Beck, M. (May I) 1995. *Nature Medicine,* University **of** North Carolina.

Moore, P.D. 1986. *Nature* 294: *385*. Quoted in S.A. Elias. 1994. *Quarternary Insect and Their Environments*, (based on work of R. Coope and others). Washington DC: Smithsonion Institution Press.

Smayda, Theodore (University **of** Rhode Island), personal communication, 1994.

Yao, **Y.** A. Hoffer, C. Chang., and A. Puga. (March) 1995. *Environmental Health Perspectives* 103(4): 366-371.