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Donald F. Boesch is a professor in and president of the University of Maryland Center for Environmental Science. He earned his B.S. in biology at Tulane University and Ph.D. in oceanography at the College of William and Mary. Before moving to Maryland in 1990, he was the first executive director of the Louisiana Universities Marine Consortium and professor of marine science at Louisiana State University. An internationally known marine ecologist, he has conducted research in coastal and continental shelf environments along the Atlantic Coast and in the Gulf of Mexico, eastern Australia, and the East China Sea.

Dr. Boesch is particularly active in extending knowledge to environmental and resource management at regional, national, and international levels. He is a science advisor to the Chesapeake Bay Program, to various state agencies in Maryland, and to other organizations in diverse coastal regions around the United States. He has served as a member of the Marine Board and the Ocean Studies Board of the National Research Council and on numerous federal agency advisory committees. He led the coastal sector team of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change and served as member of the Science Advisory Board of the U.S. Commission on Ocean Policy.

It is a real pleasure to be here. As a marine scientist, I have become interested in the global phenomena that are affecting the way we live and interact with the coastal environments in our own backyard. In talking about some of those global interactions today, I'm going to use the nearby Chesapeake Bay as my primary example.

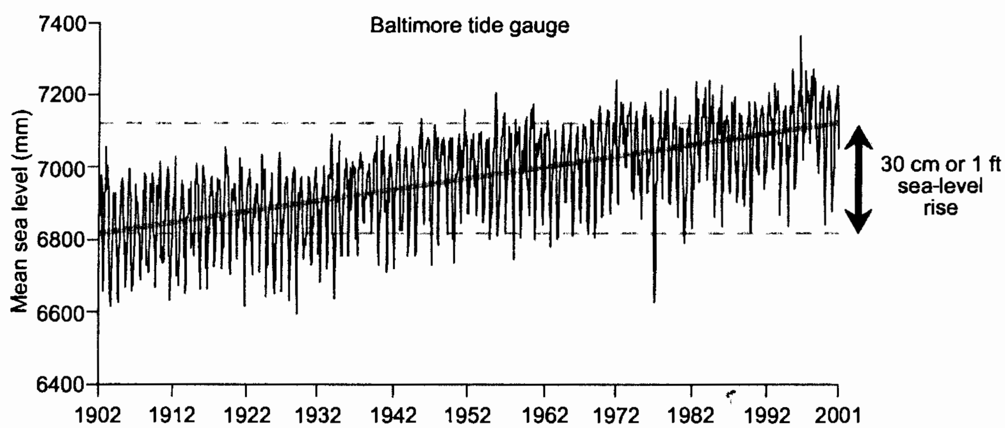
When this meeting was originally to have occurred, which was September 18 and 19, 2003, Hurricane Isabel was approaching the Chesapeake Bay across the North Carolina Barrier Islands. Isabel drove a tremendous amount of water into the lower Chesapeake Bay, with the winds initially coming from the east, blowing ocean water right into the mouth of the bay. As the hurricane progressed, ultimately passing just to the west of Washington, winds shifted from the southeast and then from the south. This created a tremendous storm surge of water up the Chesapeake Bay. When the hurricane approached Washington, the wind speeds were not particularly strong, nor was the rainfall especially heavy, so we probably could have held this meeting, had Carnegie opened up the building.

What was going on in the bay, though, was something quite different. The storm surge progressed up the main stem and lower tributaries of the Chesapeake Bay, reaching heights of almost 3 meters above sea level in some cases. As it advanced up the Potomac River, it flooded downtown Alexandria. Along the upper bay, the waterfront areas of Annapolis and the Fells Point region of Baltimore, the most historic parts of those cities, were inundated. These areas developed as colonial towns because they were near the water, not under it!

And, of course, everyone said, "Oh, my word, this is the worst flooding we have ever seen." Some of the old-timers remembered the 1933 hurricane, which had a very similar trajectory to Isabel. Indeed, one gentleman on Deal Island along the Chesapeake Bay's Eastern Shore pointed to a mark he had placed on the wall to record the level of flooding in 1933, and he said the level of flooding in 2003 was about a foot higher. So, it has gotten worse!

That may indeed be the case. If one looks at data from the Baltimore tide gauge, which has a very long record and a stable and fixed elevation, one can see that sea level has actually risen about a foot over the past century (Figure 1). Basically, the sea-level rise explains the increase in hurricane storm surge over time. More important, it serves as a wake-up call for things to come.

FIGURE 1. Relative Sea Level Rise in the Chesapeake Bay, 1902–2001



Source: Permanent Service for Mean Sea Level.

As we are busily trying to plan our lives and manage the environment, we generally assume that conditions will remain more or less constant. We are not thinking adequately about future changes.

The lesson that I am trying to communicate here is that as we are busily trying to plan our lives and manage the environment, we generally assume that conditions will remain more or less constant. We are not thinking adequately about future changes. Whether or not one believes the projections of global climate change, with all their assumptions and uncertainties, one must recognize that significant environmental changes are already taking place. More and more changes are being documented, demanding that we develop mechanisms to adapt to them. Dr. Lane made some projections about climate change for the globe as a whole; in the Mid-Atlantic region, air temperature and sea level are also projected to rise throughout the twenty-first century.

The projected sea-level rise is significantly greater than what we would expect as a result of the rise in the world ocean due to global warming. The reason is the land subsidence that has been taking place and will continue in the future. The Earth's crust in the Mid-Atlantic region bulged during the last glacial period and now is settling back down. So, we have to contend with land subsidence as well as sea-level rise. When we combine the rate of global sea-level rise with this local land subsidence, we can see in Figure 3 that the mean expected rise in sea level for the Chesapeake Bay region is almost 2 feet, or double the 1-foot rise that was seen in the past century.

This projected change has enormous implications, not only for low-lying communities, but also for critical environments that we are trying to manage and protect. For example, tidal wetlands, which occur precariously at the interface of the land and the estuary, exist in a delicate balance with the water level. To survive, wetland plants must be able to grow, trap sediments, and accrete soil material around their roots; if they accrete too much soil, the wetlands dry out, but if they do not accrete enough soil to keep pace with the sea-level rise, the wetlands are drowned. We have already seen signs of inundated marshes deteriorating, falling apart, not because of any direct impact of humans, through dredging and filling activities, for example, but because those marshes are losing that balance between soil accretion and sea-level rise. This phenomenon is also occurring in many other parts of our country and the world, most notably the coastal wetlands of the Mississippi Delta.

Sea level is not the only factor, though. All the other conditions that will change in coastal ecosystems as a result of long-term climate change have enormous consequences, including the temperature itself. Temperature influences many biological processes, but also influences where organisms are distributed on Earth. The biogeography of the world is greatly determined by temperature ranges, and it will change as temperature changes, with cold-water species retreating and warm-water species advancing poleward.

In an estuary like the Chesapeake Bay, the amount of fresh water entering the coastal zone from the land is also critical. Freshwater influx not only affects salinity gradients, but also drives circulation, because the fresh water is denser than saline ocean water. Changes in runoff and river flow affect the delivery of nutrients, sediments, and other substances. The frequency and severity of storms and the nature of coastal currents are important factors that may change as well. For example, the ecology and productivity along our West Coast is heavily governed by the California Current, which demonstrates dramatic regime shifts, as a result of decadal climatic variability, and also is susceptible to longer-term changes.

When the temperature regime changes, the door opens to other kinds of biological changes. One such change is the establishment of invasive species that might have previously been excluded. In this morning's news is the capture two days ago of a northern snakehead fish in the Potomac River just a few miles downstream of Washington. Two years ago, northern snakeheads, fish native to Asia, were found in a small pond in Maryland, but they were eradicated before they could spread. However, this was the third northern snakehead recovered from the Potomac this year, suggesting that a population of this invader has become established. So, you AAAS Fellows here in Washington, be careful when you walk down along the banks of the Potomac because this is the legendary fish that, according to the press, walks on land, breathes air, and eats small children. Although this invader was introduced by human action rather than changing climate, it is indicative of the rapidity and consequences of biological invasions, some of which are facilitated by changing climate.

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Climate change will complicate our already challenging efforts to restore and manage imperiled coastal ecosystems. The U.S. Commission on Ocean Policy, appointed by the president to address a Congressional mandate, has just issued a draft final report that deals comprehensively with a wide range of issues related to the state of our nation's oceans and coastal resources, environments, and communities. Initially, the commission's work was seen as an effort to reignite interest in our ocean environments and investments in ocean research, but it became in the end a much more sober appraisal of the problems with which we are dealing along the U.S. coast: not only invasive species, sea-level rise, and wetland losses, but also pollution, habitat losses to development, and overfishing, which affects not only the stocks that we fish, but the ecosystem as a whole. The commission's report calls for a more integrated approach to dealing with those issues and problems, using ecosystem-based management (the final report is posted at www.oceancommission.gov).

Despite the report's emphasis on an integrated approach, one can find scant mention of the consequences of climate change as something that we have to factor into the more effective management of coastal resources. Now, this could be because the commission wished to avoid political controversy, but it is also, I think, because most people who work on the day-to-day problems we have created are preoccupied and overwhelmed by them. Many well-meaning practitioners have difficulty adding another layer of complexity—such as what climate change may mean—to what they are already struggling to achieve.

The report, which I encourage you to read, espouses a number of quite noble management principles, such as sustainability, a precautionary approach, and stakeholder engagement that, if actually put into practice, would greatly improve the effectiveness of coastal environmental protection and resource management. Some recommendations of interest to this audience are, first, strengthening the basis of science for managing the ocean and its resources, and second, applying new approaches, such as adaptive management, which involves learning by doing and puts great emphasis on understanding outcomes and using that knowledge in subsequent policy development and management decisions. Implementing these recommendations will create enormous opportunities for the scientific community.

A particularly important factor affecting coastal ecosystems around the world results from what has been called the nitrogen cascade. Loading of the nitrogen cycle with reactive nitrogen produced by human activities became a phenomenon of global proportions during the second half of the twentieth century, growing more rapidly than even the build-up of greenhouse gases. In a very short order, humankind has doubled the amount of reactive nitrogen in the biosphere. This recent abundance of reactive nitrogen cascades from one medium to another, from air to land to water, with significant consequences to ecosystems and human well-being. The nitrogen cascade has enormous consequences for the ten major issues that Dr. Neal discussed, particularly those at the top of the list, namely, energy, water, food, and environment.

The human-fixed nitrogen comes from two basic sources: one is that needed to support food production, generally through the synthesis of ammonia for fertilizers from nonreactive dinitrogen gas in the atmosphere. The other source is that released as a byproduct in the combustion of fossil fuels, which at high temperatures oxidizes nitrogen in the air. Nitrogen from those two sources cascades through ecosystems with enormous consequences. Nitrous oxides are a precursor to the formation of ground-level ozone, thus affecting human health and forest productivity. Deposition of oxidized nitrogen from the atmosphere affects plant communities and can acidify soils and surface waters. Nitrate leaches or runs off fertilized farm fields, affecting the quality and use of both ground and surface waters.

At the end of this cascade is the coastal zone, which receives the nitrogen that has not been absorbed elsewhere in the system. Excess nitrogen is one of the main causes of the coastal ecosystem degradation that we see around the world. It results in algae blooms, some of which produce toxins that are harmful to humans or reduce the light available for underwater plant growth. Degradation of the abundant organic matter produced can ultimately deplete the life-sustaining oxygen in the water. A so-called dead zone, containing very little if any dissolved oxygen, occurs every summer in the deeper parts of the Chesapeake Bay.

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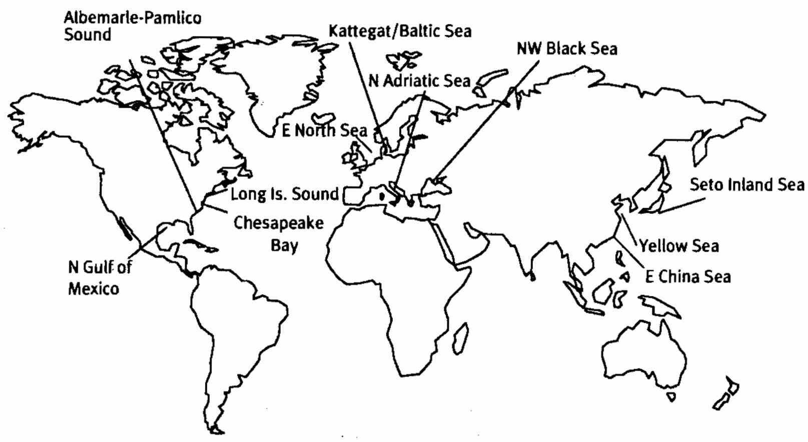
If we look around the world at where coastal ecosystems have deteriorated rather dramatically, we can see that they are closely related to areas where the total reactive nitrogen produced by humans has increased rapidly, particularly owing to the use of industrially produced fertilizers (Figure 2). Fertilizers, of course, have great benefits for humankind, because without them we would scarcely be able to feed the 6.5 billion people we have in the world, much less the 10 billion people that Dr. Lane showed you in the projections for later this century. But, just as we will need fertilizers, we will also need to learn to avoid some of their negative consequences.

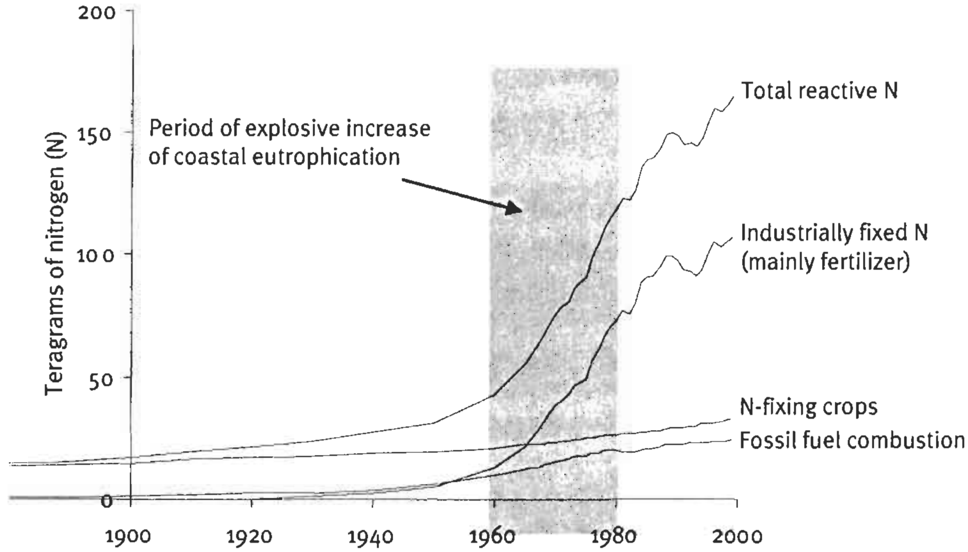
Atmospheric discharges of oxidized nitrogen are clearly related to industrial development, power gener-

FIGURE 2. Coastal Seas Experiencing Large-Scale Nutrient Overenrichment



Source: D.F. Boesch, "Challenges and opportunities for science in reducing nutrient over-enrichment in coastal ecosystems," Estuaries 25 (2004), pp. 886–900.

FIGURE 3. Coincidence of Degradation in Coastal Ecosystems around the World and Global Increases in Production of Fertilizers and Combustion of Fossil Fuels



Source: D. F. Boesch, "Challenges and opportunities for science in reducing nutrient over-enrichment in coastal ecosystems," Estuaries 25(2004), pp.886–900.

The Chesapeake is leading the world in trying to figure out how to reduce these excessive nutrient inputs in order to restore the coastal ecosystem.

ation, automobile emissions, and the like (Figure 3). This worldwide explosion of coastal overenrichment is presently evident mainly in North America and Europe, and it affects rather large systems, including the Gulf of Mexico, the Baltic Sea, and portions of the Mediterranean.

Almost two-thirds of U.S. estuarine and bay environments have been degraded as a result of overenrichment with nutrients, particularly nitrogen. This is the cause of the so-called Gulf of Mexico dead zone or hypoxia, which is related largely to the agricultural inputs of nitrogen 1,500 kilometers upstream in the Mississippi River, from Iowa, Illinois, Minnesota, Wisconsin, and Ohio. When Dr. Lane was the president's science adviser, there was an assessment of Gulf hypoxia, and a multistate agreement was reached at the end of the Clinton Administration to reduce the sources of nutrients in order to mitigate the effects downstream. However, little has yet been done to implement this agreement.

So, what does this mean for the world, looking ahead to 2033? One of the indicators we can project globally is the demand for cereal crops (Figure 4). That demand will grow rapidly in developing countries over the next 30 years, because of the growing populations and the growing desire of developing populations to live our lifestyle. Although we may hope that they will not eat as much environmentally costly and unhealthy animal protein as we in the United Sates now do, the rising demand for food and, therefore, fertilizer is clearly a trend with which we will have to contend. And, interestingly, as one can see in the projections, developing nations will continue to fall short of meeting their own demands from their own production. This shortfall has implications for the United States, as the increased demand for agricultural products drives our exports and, therefore, has consequences on our domestic environment through the nitrogen cascade.

Another global indicator is the projected level of NO_X emissions, as demand for energy rises. In Asia, for example, as people use more internal combustion–powered vehicles and demand more electrical power, the emissions of NO_X are projected to increase dramatically in the 30-year time horizon (Figure 5).

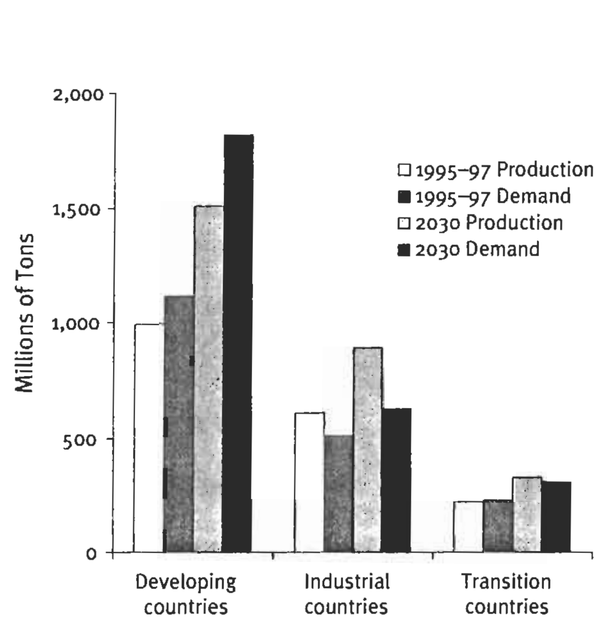
Bringing these projections again closer to home for the Chesapeake, we have developed plausible scenarios to reduce nitrogen loading over the next 30 years. The Chesapeake is leading the world in trying to figure out how to reduce these excessive nutrient inputs in order to restore the coastal ecosystem. Through an effort that we call Chesapeake Futures, the scientific community in the region asked: What are the changes in technology that we could apply? What are the changes in lifestyle and development patterns that we could propose as options that would reduce the nitrogen inputs into the system? We examined three scenarios (Figure 6). The first scenario basically assumes that recent trends will continue unchanged, meaning that we're doing about as much as we can do. Under that scenario we will actually lose ground as nutrient loading increases as a result of population growth and unabated sprawl. The middle scenario assumes that we achieve the management objectives that were in place in 2000.

The third scenario introduces what we thought were feasible alternatives. These might not be accomplished right away, but over the next 30 years could well be accomplished. For example, atmospheric emissions of NO_X could be significantly reduced through developing the kinds of energy alternatives that Dr. Lane mentioned, such as greater use of hybrid vehicles, and maybe even hydrogen fuel-cell vehicles. Through such feasible innovation in agriculture, waste treatment, and growth management, we could significantly shrink the dead zone, the volume of hypoxic water, in the Chesapeake Bay.

Whichever outcomes could actually be achieved—either losing ground or, in the most optimistic case, gaining substantial ground—nitrogen inputs would remain well above those experienced by the pristine bay. Nonetheless, the feasible alternatives scenario would yield significant improvements in the environmental quality of Chesapeake Bay.

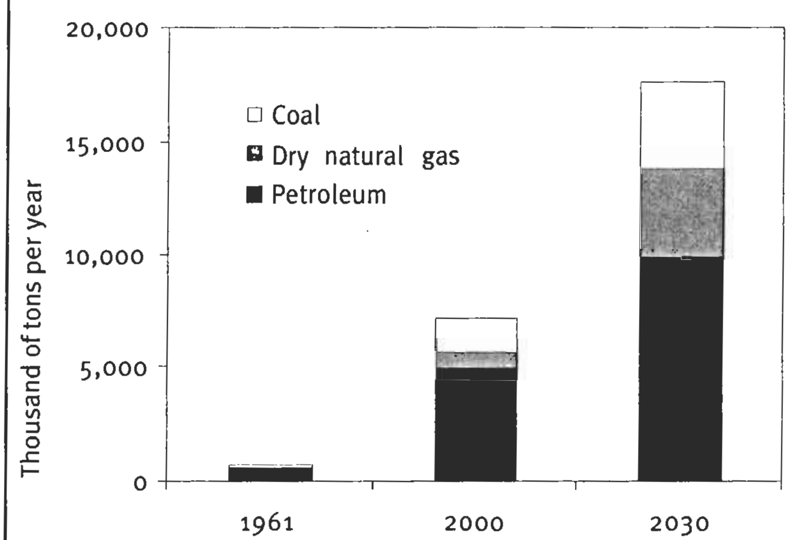
Undoubtedly, we as scientists have some formidable challenges ahead contributing to the improved management of coastal ecosystems. Perhaps our first step is to develop the right mindset to facilitate change. Let me call this the "Pasteurization" of our science. That notion comes from a book entitled *Pasteur's Quadrant,* by

FIGURE 4. World Cereal Demand and ProductionProjected to 2032



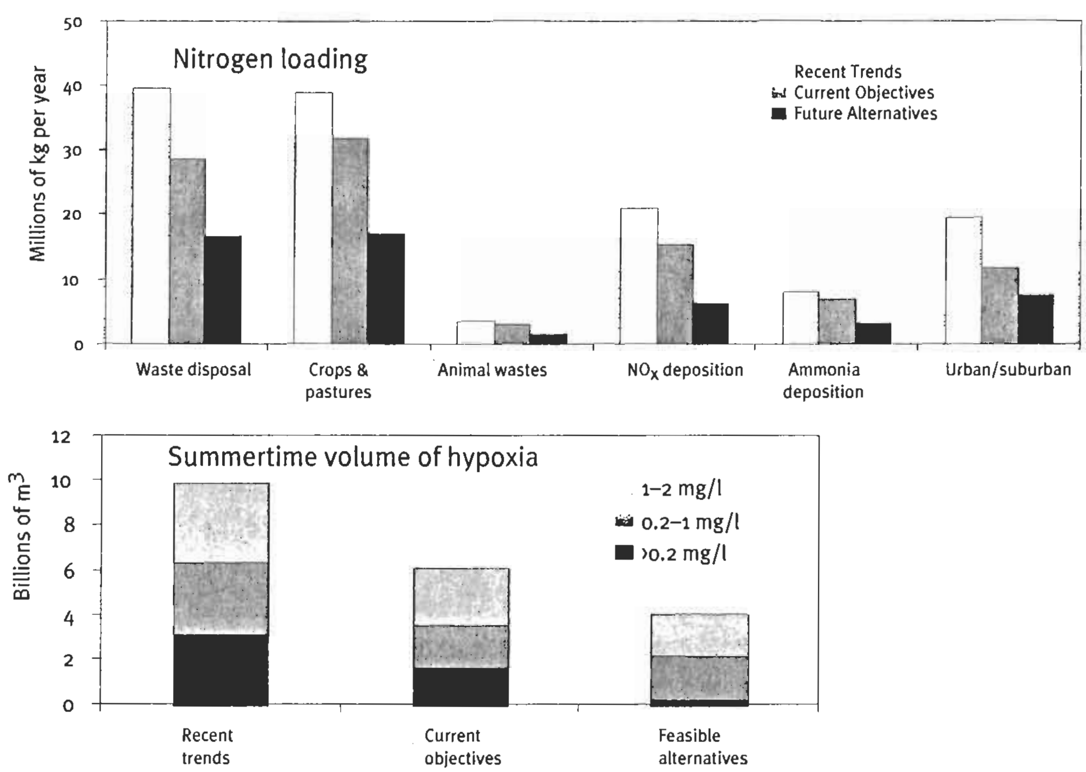
Source: R. N. Roy, R.V. Mistra, and A. Mntanez, " Decreasing reliance on mineral nitrogen —yet more food," Ambio 31(2002), pp. 177–83.

FIGURE 5. Emissions of Nitrogen Oxides in Asia Projected to 2030



Source: M. J. Bradley and B.M. Jones, Ambio 31(2002), pp. 141–49.

FIGURE 6. Nitrogen Loadings to the Chesapeake Bay by 2030 under Three Scenarios and the Effects of These Scenarios on the Oxygen-Depletion of Bottom Waters



Source: D. F. Boesch and J. Greer, Chesapeake Futures: Choices for the 21st Century, Edgewater, Md.: Chesapeake Research Consortium, 2003.

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Donald Stokes (Brookings Institution Press, 1997). Stokes observed that some scientific advances driven solely by fundamental curiosity (think of Nils Bohr) eventually resulted in useful applications and that society can also benefit from a rather uncurious technological application of scientific observations (think of Thomas Edison). However, the simultaneous quest for scientific knowledge and practical application can create marvelous synergy. That was Louis Pasteur's approach. Pasteur was very strongly driven not only by basic curiosity about the way the world works and the understanding of basic principles and processes, but also by his very fervent desire to use this knowledge for the benefit of human society. I think that approach is a model not only for our own individual ways of thinking about these environmental problems, but also for our institutions to foster more use-inspired research as we move forward.