The Winners of the Blue Planet Prize
1996

1996

Blue Planet Prize

Dr. Wallace S. Broecker (U.S.A.)

Newberry Professor of Geology at Columbia University, Lamont-Doherty Earth Observatory

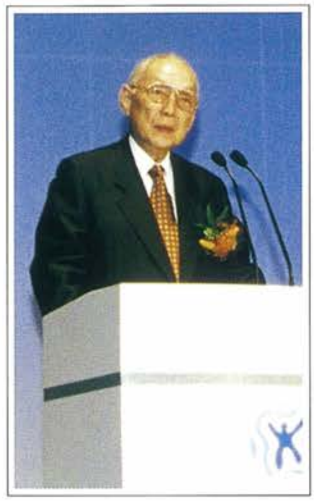
The M.S. Swaminathan Research Foundation (MSSRF) (Established in India)

Excerpts from a book of stories and pictures by children from around the world formed the basis of the 1996 awards ceremony slide presentation. The issues of humankind versus nature and of civilization coming to terms with environmental problems were put in clear focus by the messages from the children to adults about how they want the Earth to be left for future generations.

Professor Kenichi Fukui, Nobel laureate and a councillor of the Asahi Glass Foundation, gets the party started with a toast.

His Highness Prince Akishino and Her Highness Princess Kiko congratulate the laureates.

The awards ceremony is opened by Jiro Furumoto, chairman of the Asahi Glass Foundation.



Prior to the awards ceremony, the award recipients are interviewed by members of the press. From right to left: Dr. Swaminathan; Dr. Broecker; Jiro Furumoto; and Osamu Shiragami.

Dr. Swaminathan participates in a follow-up discussion after delivering his lecture on sustainable development.

Walter F. Mondale (left), ambassador of the United States of America to Japan, and Kuldip Sahdev, ambassador of India to Japan, address the audience at the awards ceremony.

During his lectures, Dr. Broecker explains his theory of the ocean's circulation system.

Profile

Dr. Wallace S. Broecker

Newberry Professor of Geology at Columbia University, Lamont-Doherty Earth Observatory

Education and Academic and Professional Activities

1953	Received B.A. from Columbia College of Columbia University
1958	Earned doctorate degree from Columbia University
1959	Became assistant professor at Columbia University
1961	Became associate professor at Columbia University
1964	Became full professor at Columbia University
1977	Named the Newberry Professor of Geology, Columbia University
1979	Elected to the National Academy of Sciences (U.S.A.); Elected chairman of the Geochemical Society (U.S.A.)
	Maurice W. Ewing Medal of the American Geophysical Union
1986	Alexander Agassiz Medal of the National Academy of Sciences; Urey Medal of the European Geophysical Union; U.M. Goldschmidt Award, Geochemical Society
1987	Vetlesen Prize, G. Unger Vetlesen Foundation
1990	Wollaston Medal of the Geological Society of London
1995	Roger Revelle Medal of the American Geophysical Union
1996	National Medal of Science

Through his systematic analysis of measurements of carbon and its isotopes, Dr. Broecker has contributed to the understanding of chemical cycles in the oceans. In the 1980s, he elucidated the importance of the "great conveyor belt," a global ocean current that envelops the Earth, extending from the North Atlantic and circulating through the Indian and Pacific oceans. Often called Broecker's Conveyor Belt, the importance of this phenomenon to the Earth's climate was first recognized by Dr. Broecker. In addition, he clarified how the surface waters and the deep waters of the ocean circulate in a millennia-duration cycle.

Dr. Broecker also pioneered chemical and isotopic methods to determine the rate of gas exchange between the atmosphere and the ocean, permitting the rate of fossil fuel CO_2 uptake to be calculated. Among the first to recognize the significance of the global carbon cycle, Dr. Broecker devised a method of analyzing samples of ocean water by using radiocarbon measurements, allowing the rate of mixing of fossil fuel CO_2 into the body of the ocean to be analyzed.

In his capacities as teacher and pioneering researcher, Dr. Broecker has offered his ideas and guidance to hundreds of scientists around the world. Describing humankind's emission of greenhouse gases as "playing Russian roulette with the climate," he was among the first to sound the alarm on global warming.

Essay

Our Burden of Responsibility

Dr. Wallace S. Broecker

April 1997

Our Blue Planet is entering what promises to be its most critical century. So far, our planet has been largely in the grip of natural forces which have governed for 4.5 billion years. Ready or not, management of the planet is falling into our own hands and, unfortunately, we are more prone to be plunderers than stewards. Further, we have yet to stem the alarming population increases which threaten to outstrip the planet's capacity for food production.

Were our galaxy endowed with Eternal Observers, their attention would certainly be focused on our beautiful Blue Planet. Having witnessed newly emerged intelligent beings take the reins on other planets, these Observers would debate whether or not we could pull off this critical transition with only minimal damage. Or, like so many others in the galactic past, would we botch the job. Would scores of species vanish? Would radioactive contamination threaten those which survived? Would the lands be scarred, the oceans polluted, and the smoothly running geochemical cycles upset? Past observations by the Observers revealed that only in rare cases were the inhabitants able to put aside their tribalism; control their burgeoning numbers; and establish a harmonious relationship with fellow organisms. Our hypothetical Observers would note that this poor success record was directly attributable to rapidly accelerating population growth. In order to keep pace with the exponential increase in their numbers, attention would have been riveted on satisfying their immediately needs. Long-term planning would fall victim to expedience, dogma, and greed.

It appears that our Blue Planet is proving no exception to this dire scenario. We have achieved the ability to eliminate other mammals with whom we once competed for survival. We've learned to annihilate our enemies with nuclear bombs; despoil our forests; harness our most awesome rivers; and squander the planet's once vast reserves of fuel, minerals, and water. As a consequence of these ravages, our atmosphere is being loaded with greenhouse gases and our soils with poisons. Even though aware of the lasting damage our activities can cause our planet, as push comes to shove, we allow more immediate problems to divert our attention. Unfortunately, the long-term solutions prove to be in direct conflict with short-term needs.

I consider population growth to be by far the most important issue confronting us. Whether the threat is compromised climate due to excess atmospheric CO_2 or a global social order severely strained by hunger and overcrowding, the situation escalates exponentially with the number of people on the planet. At present, the "good life" requires enormous energy consumption. Nearly all this energy is currently derived from fossil fuels. Roughly half of the CO_2 we generate over the next century by burning these fuels will remain in the atmosphere. Since numerous uncertainties still plague our climate models, we cannot adequately predict the consequences of adding this CO_2 to the atmosphere. While I am expert only in the area of climatology, my layman's knowledge of the problems created by hunger and overcrowding tells me that their consequences could easily dwarf even those created by climate change.

I usually consider myself a bubbling optimist, but when it comes to assessing our Blue Planet's future, pessimism sets in. Much like doctors opting to treat serious illnesses with Band-Aids and sugar pills, we are proposing solutions which fail to address the root cause of the problem. It is futile to point fingers of blame for we all share responsibility for painting ourselves into a very small corner. Attaining and preserving human dignity should be foremost in the minds of all people and, ironically, it is this same exemplary objective which inhibits the ability to stem population growth, energy use, and the exploitation of natural habitats. Indeed, it propels us toward even more growth in every sector.

While the burden of guilt must be shared by all, in some areas charges can be leveled at extreme offenders. The United States, for example, uses far more energy than necessary. We acknowledge this, but our political leaders are afraid to implement the sizable energy tax required to bring the usage under control. The Vatican hierarchy doggedly maintains its archaic position on birth control. Japan looks aside while its companies buy wood and hence destroy forests around the world. China allows military hardware to be exported to warring nations. And there is the fear that profiteering Russians engage in the sale of plutonium to terrorist organizations.

A perfect example of our Band-Aid and sugar pill approach is the 1991 Rio Accord on CO_2 emissions. Even if implemented and rigorously adhered to, it constitutes only a 20% solution. Without this agreement, the CO_2 content of the atmosphere would reach perhaps 700 ppm by the year 2100. With it, the rise would be held to about 560 ppm (i.e., 20% lower). While this reduction would ease the threat to climate, it would by no stretch of the imagination solve the problem. Further, were the Clinton administration to propose adherence to the Rio plan, Congress would surely balk. And if it were implemented, the American people would likely express their heated discontent at the ballot box.

No, I am afraid that our ever more democratic world is incapable of exerting the strict discipline necessary if we are to move with sufficient speed to quell the dangerous spiral of growth. Further, even if a benevolent global planning authority were created, its chances of survival would be slim indeed.

What will happen? Likely we will keep our heads in the sand hoping that the transition will be accomplished with only minor damage and pain. Surely there is a fair possibility that such a scenario will come to pass. But we indulge in a dangerous game. In the United States we call it Russian Roulette. It could go very wrong.

What would it take to reduce the extent of my pessimism? The answer is, a series of incredible actions by powerful people. For example, what if the Pope were to announce that he had received a clear directive from on high that immediate measures be put into place designed to reduce the global birthrate. Or, were Albert Gore to become President of the United States and declare that his administration would enact very tough policies directed toward remedying the dire environmental problems outlined in his book, *Earth in the Balance*. Or were Microsoft's Bill Gates to allocate 95% of his enormous income to help educate

Africa's poor? Or were a future prime minister of Japan to announce that henceforth his country would pay developing countries more to save their trees than they would receive by selling them.

Put simply, as we are being forced to take the reins of our planet's future, we have only ourselves to turn to. The Blue Planet's message to us is unequivocal: we are forcing it to the brink and we must now take the helm, accepting the sacrifices required to insure its future.

Lecture

Will Our Ride into the Greenhouse Future Be a Smooth One?

Dr. Wallace S. Broecker

(As submitted to *GSA TODAY*)
Revised February 1997

Abstract

The climate record kept in ice and in sediment reveals that since the invention of agriculture some 8,000 years ago, climate has remained remarkably stable. By contrast, during the preceding 100,000 years, climate underwent frequent, very large and often extremely abrupt shifts. Furthermore, these shifts occurred in lock step across the globe. They seem to be telling us that the Earth's climate system has several distinct and quite different modes of operation and that it can jump from one of these modes to another in a matter of a decade or two. So far, we know of only one element of the climate system which has multiple modes of operation, namely, the oceans' thermohaline circulation. Numerous model simulations reveal that this circulation is quite sensitive to the fresh water budget in the high latitude regions where deep waters form. Perhaps the mode shifts revealed in the climate record were initiated in the sea.

This discovery complicates predictions of the consequences of the ongoing buildup of greenhouse gases in the atmosphere. If the major climate changes of glacial time came as the result of mode shifts, can we be certain that the warming will proceed smoothly? Or is it possible that 100 or so years from now, when our ancestors struggle to feed the 15 or so billion Earth inhabitants, that climate will jump to another of its states. It is difficult to comprehend the misery which would follow on the heels of such an event!

The debate regarding the eventual consequences of the ongoing buildup of greenhouse gases in the atmosphere concerns the magnitude of the coming changes. Most atmospheric scientists agree that the warming during the coming century will be sufficiently large to pose serious difficulties. But, because to date the warming has been smaller than predicted by most general circulation models, a vocal minority pooh-pooh this supposed threat. On the other hand, little debate has occurred regarding the shape of the path climate will follow as CO_2 and other infrared-absorbing gases build up in our atmosphere. Whether large or small, nearly everyone assumes that the warming will be a smooth climb with climate keeping pace with the ever increasing strength of the greenhouse blanket. But will it? Certainly the Earth's climate system has proven beyond any doubt that it is capable of undergoing abrupt jumps from one state of operation to another. Can we be sure that it won't respond to our push by lurching into another of its operational modes?

Figure 1 Oxygen isotope ratio record in ice from a three-kilometer-long core taken by the European GRIP group at the Summit site in central Greenland (Dansgaard et al., 1993). This ratio is related to air temperature; the greater the depletion in the heavy isotope the colder the temperature. Based on the measurements of temperature in the bore hole, it has been possible to demonstrate that the mean air temperature in Greenland must have been 16 °C colder during glacial time than during the present interglacial (Cuffey et al., 1995). The time scale was obtained by counting annual couplets in the ice (Meese et al., 1994). Note that only during the last 10,000 years has Greenland's air temperature remained nearly constant. By contrast during the last ice age and during the latter portion of the last interglacial, large and rapid shifts occurred. Greenland's air temperatures never paused at a single value for more than 1,000 years.
The electrical conductivity of Greenland ice is set by the amount of acid present. Measurements made on the GISP ice core (a duplication of the GRIP core 40 kilometers away) reveals that during the very cold intervals the electrical conductivity fell to near zero values (Taylor et al., 1993). The reason is that the rain of $CaCO_3$ contained in the wind-blown dust exceeded the amount required to neutralize the acid fallout. Because electrical conductivity can be measured continuously by scratching the ice with a pair of sharp electrodes, a very detailed record was obtained. As shown here, this record reveals that the transitions between climate states were extremely abrupt, being completed in a few decades. Furthermore during this brief transition period, the input of dust (and presumably also global climate) flickered on the time scale of just a few years.
The rapidly accumulating (1 m/10^3 years) sediments in the Santa Barbara basin record each of the so-called Dansgaard-Oeschger events seen in the Greenland ice core record. Behl and Kennett (1996) established this based on the alternation between sections with and without annual laminations. The laminated sections represent times when the pore waters in the sediment were anaerobic, preventing burrowing by bottom dwelling worms. The absence of laminations in the intervening sections reflects times when the pore waters were oxygenated, allowing burrowers to thoroughly stir the sediment. The alternations match almost perfectly the alternations in Greenland air temperature. During very cold intervals, such as the Younger Dryas, waters rich in O_2 must have descended into the North Pacific's thermocline. As today's surface waters of the northern Pacific are too low in salt content to permit direct ventilation of deeper portions of the thermocline, these alternations suggest major changes in the salinity distribution in this region of our planet.

A Message from Greenland

A clear demonstration that the climate system can jump from one state to another comes from a record kept in Greenland ice (see Fig. 1). European and American teams have drilled through the entire thickness of the Greenland ice cap. The most recent and best documented of these records is a pair of three-kilometer-long ice cores from right on the summit of Greenland. These cores provide not only a record of climate in Greenland but also implications regarding climate in other places on the globe that extend back 110,000 years before the present. As precise counting of individual couplets of winter and summer snow extends back to at least 45,000 years, little question exists regarding the chronology of this ice core (Meese et al., 1994).

The isotopic composition of this ice is related to the air temperature over Greenland. For the last 10,000 years, Greenland has enjoyed, at least compared to the previous 100,000 years, a very stable climate. There was one cold blip 8,000 years ago; but other than that its climate has remained pretty much unchanged. But prior to 10,000 years ago, the climate leaped back and forth between states of intermediate cold and extreme cold. The median temperature at this site during the ice age has now been well established through thermal profiles in the ice itself to have been on the average 16 °C colder than during the last 10,000 years (Cuffey et al., 1995).

Further, during the last five years, evidence from a variety of investigations has clearly demonstrated that these changes were not confined to Greenland; rather, they were global! Before reviewing the evidence for these far-reaching impacts, let us consider the rapidity of these changes. This is best done by focusing on the last warming, i.e., that which ushered in the present interglacial. Shown in Fig. 1 are blow-ups of measurements of the electrical con-

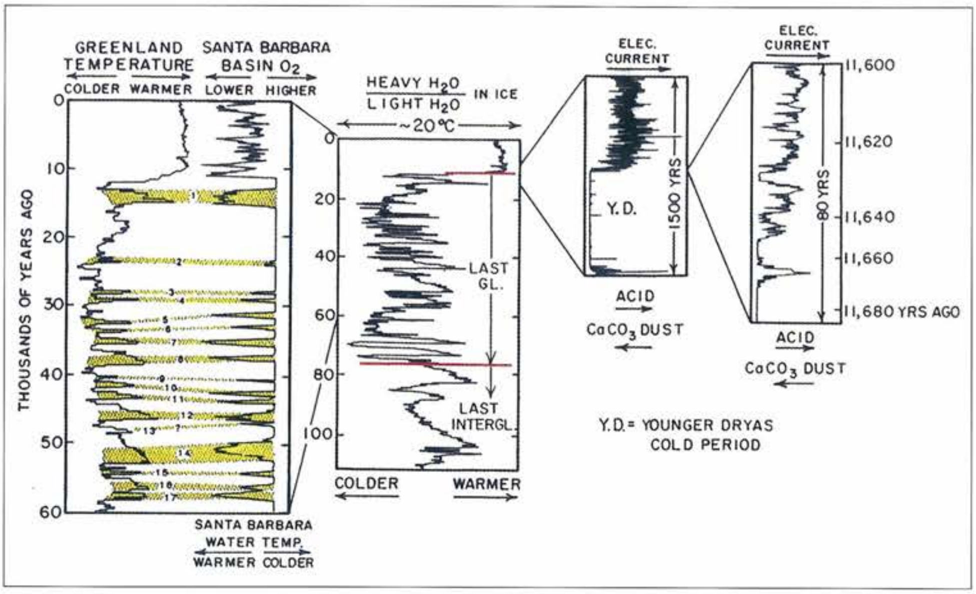
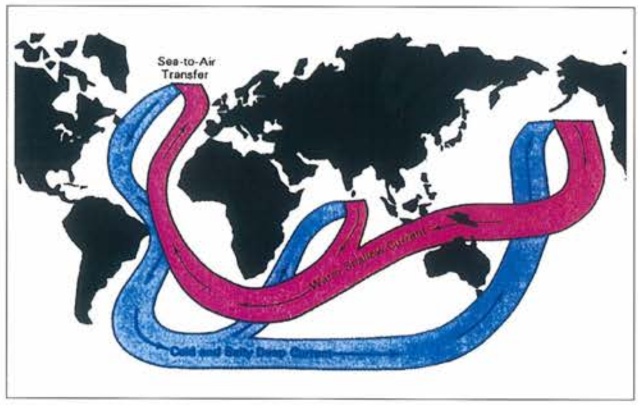


Figure 1

Figure 2 The great ocean conveyor carries warm water to the region around Iceland where cooling by cold Canadian air masses densifies the water, allowing it to sink to the bottom forming a southward-moving water mass. The flux of water (20 million cubic meters per second) matches that of 100 Amazon rivers and is equal to the flux of global rainfall. So immense is the heat released to the atmosphere that it maintains northern Europe 5°C to 10°C warmer than it would be were the conveyor to shut down.



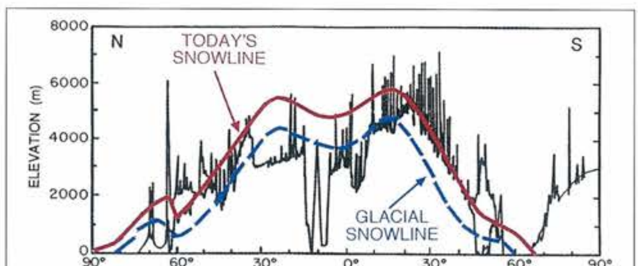


Figure 3 The highest mountains at all latitudes along the cordillera of the Americas are currently capped by glaciers. At elevations above the 0°C isotherm, more snow accumulates than melts (or evaporates). The solid line shows how the elevation marking the lower boundary of net accumulation varies with latitude. Reconstructions based on geomorphic evidence (see dashed line) show that during times of peak glacial cooling the snowline on these mountains descended almost one kilometer. Combined with oxygen isotope composition of glacial age ice recovered by Thompson et al. (1995) from 6 km elevation on the tropical Andean mountain, Huascarán, this lowering suggests not only colder, but also drier conditions in the tropics during glacial time.

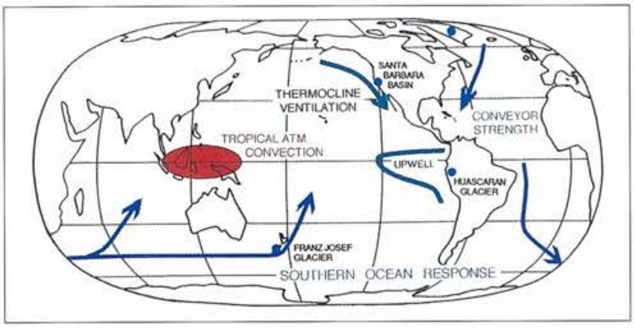


Figure 4 A possible causal chain leading to the global climate change is as follows. A sizable reduction in the strength of the Atlantic's conveyor had repercussions throughout the ocean. Included were changes in operation of the upper ocean as recorded in the Santa Barbara basin. One impact of these changes may well have been an increase in the strength of upwelling in the east equatorial Pacific. We know from studies of the El Niño periods that changes in upwelling have wide repercussions in the tropical atmosphere. I propose that, somehow, the ocean upwelling change led to a reduction in the rate of delivery by tropical convection of water vapor to the atmosphere. As water vapor is the Earth's dominant greenhouse gas, this reduction would cool the Earth.

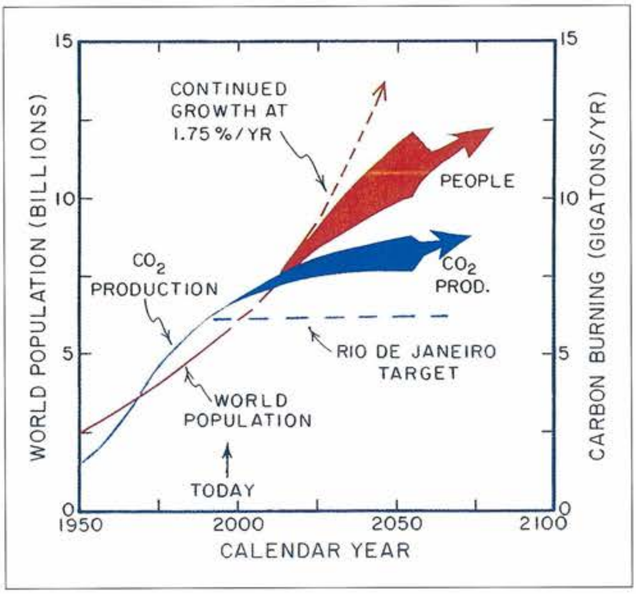


Figure 5 Population is currently increasing at the rate of 1.75% per year. While this rate is projected to gradually decrease, by the middle of the next century population will reach somewhere between 10 and 15 billion. Despite a desire to hold CO_2 production from fossil fuel burning to the 1990 level, the demand for energy is bound to rise as the number of people rises. It will likely reach at least 7.5 gigatons of carbon per year by the mid-21st century.

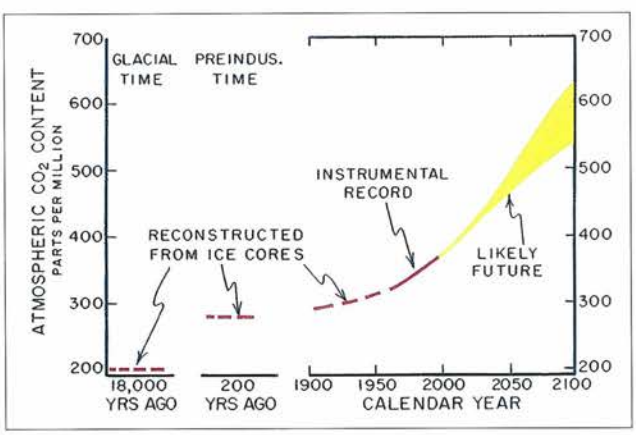


Figure 6 During the last glacial period, the CO_2 content of our atmosphere was only 200 ppm. Upon deglaciation it rose to about 280 ppm and has hovered about this value until the onset of the industrial revolution. Due mainly to fossil fuel burning, it has risen over the last 100 years to its current level of 365 ppm. This rise will continue, reaching double its pre-industrial value by the end of the next century.

ductivity record for one of the Greenland ice cores (Taylor et al., 1993). This property of the ice was measured in great detail by scratching a fresh surface of the ice with a pair of electrodes. This record provides a measure of the ratio of the fallout of acids to that of calcium carbonate-bearing dust. During the Younger Dryas cold event (YD), the rate of $CaCO_3$-bearing dust infall was so high that it totally neutralized the acid. Therefore the electrical conductivity was very low. And then at the onset of the present warm period, the dust input dropped way back, allowing the acids to dominate. As the protons from the acid sustain the electrical conductivity in ice, the conductivity is high. So we see that it was not only Greenland's air temperature which changed but also the dustiness of the air masses reaching Greenland. The isotopic fingerprint of this dust is consistent with an origin in the Gobi Desert (Biscaye et al., in press). If so, Asian climates must also have undergone abrupt changes.

In the blow-up on the extreme right of Fig. 1, are shown the calendar ages defined by annual layer counting. This allows the duration of the transition interval to be well documented. Clearly, the onset of this warming was abrupt. The initial change took place in only two or three years, but then the climate flickered, the dust came back in spurts before the situation stabilized in the low dust state. The entire transition took place in less than three decades (Taylor et al., 1993).

Ice cores also tell us something about tropical climates. They do so because air bubbles trapped in the ice contain methane, a gas which is currently produced in rice paddies and cow pastures. But, prior to the invention of agriculture, the major source of methane was swamps. Currently, many of these swamps are located in the temperate latitudes of the northern hemisphere. During glacial time when the planet was very cold, all these northern swamps were either covered by ice sheets or frozen into tundra. Hence they could not have been methane producers. So, during the Younger Dryas, most methane must have been produced in the tropics. In concert with the big warming at the end of this last cold event, the methane content of the Earth's atmosphere jumped from slightly below 500 up to about 750 parts per billion. I think that this rise was driven, at least in part, by a wetting of the tropics, i.e., to an increase in the size and number of methane-producing swamps and soils. It's therefore interesting to explore the relationship between the timing of this methane jump and the abrupt warming in Greenland. A former graduate student of mine, Jeffrey Severinghaus, working in the laboratory of Michael Bender at the University of Rhode Island, made a major discovery when he found a means by which in these same air bubbles he could obtain a measure of air temperature change in Greenland. He used these measurements to show that Greenland's warming began no more than a decade or so before the onset of the increase in methane. Somehow, when Greenland suddenly got much warmer, the tropics suddenly got wetter. So the impacts of this mode change extended, from Greenland at least, down into the tropics.

Climate Change: Global as well as Large and Abrupt

A friend of mine, George Denton of the University of Maine, working with a colleague, Chris Hendy, studied a very interesting moraine left behind by a major advance of New Zealand's Franz Josef Glacier. The expansion of interest extended down the steep valley toward the Tasman Sea and created at its outer limit the Waiho Loop moraine . The rock rubble making up this moraine is underlain by lots of wood. Denton and Hendy (1994) postulate that as the glacier advanced, it moved through a forest, tearing out trees and bulldozing them to its terminus. They obtained 25 radiocarbon measurements on separate pieces of this wood and determined the age of this basal wood deposit to be 11,150 plus or minus about 50 ^{14}C years. This is very close to the radiocarbon age that's been obtained in the northern hemisphere for the onset of the Younger Dryas cold interval (Hajdas et al., 1995). So, Denton would say that the southern hemisphere knew about this event; the mountain glaciers responded to a substantial lowering of the zero degree isotherm. To achieve this descent required a substantial southern hemisphere cooling.

Quite recently, a spectacular set of results from sediments in a basin just off Santa Barbara, California, verifies that this phenomenon was widespread and strong, not only during the Younger Dryas, but also for the entire series of so-called Dansgaard-Oeschger (i.e., D-O) events. These events, named in honor of two of the heroes of ice core research, punctuated the period between about 65,000 and 25,000 years ago. Previously it had been impossible to duplicate this ice record only in ocean sediments from the northern Atlantic (Bond and Lotti, 1995). The reason is that for the most part they accumulate so slowly that the stirring by worms obliterates millennial duration events. After much begging, Jim Kennett, of the University of California at Santa Barbara, convinced the deep-sea drilling program to spend one day drilling two shallow holes in the Santa Barbara basin. This brief effort produced a gold mine of information. As these sediments accumulated at a rate of about 1 meter per 1,000 years, they have adequate resolution to fully preserve the Dansgaard-Oeschger events. And indeed they did. As shown by Behl and Kennett (1996), during each of the warm phases, the sediment shows annual banding while during each of the cold phases stirring by bottom dwelling organisms homogenized the sediment. This suggests that during the warm phase of each D-O cycle the O_2 content of the water filling the Santa Barbara basin was sufficiently low and the rain rate of organic matter sufficiently high that the sediments were anoxic. Thus, burrowing organisms were excluded. By contrast, during each of the cold phases (including the YD), the pore waters in the upper sediments must have been oxygenated. To me this suggests that during the cold phases conditions in the northern Pacific were quite different than now. The low salinity surface waters which currently cap this region and thereby prevent direct ventilation of the main thermocline must have been replaced with saltier water allowing the northern Pacific to operate much as the northern Atlantic does today. And what Behl and Kennett (1996) found is that 16 of the 17 D-O events in Greenland ice core are clearly present in the Santa Barbara record.

So, what does this tell us? To me this supplies an extraordinarily important piece in the puzzle. The ventilation of the North Pacific's thermocline (by this I mean, the sinking of waters from temperate latitudes to intermediate depths) increased greatly during the cold phases of the D-O events (i.e., the intervals during which laminations disappear). So the cold spells in Greenland are matched in the North Pacific Ocean by what must have been a radical change in the style of upper ocean circulation.

To summarize, I've recapped what I consider to be the highlights of evidence for the global extent, large magnitude, and abruptness of these D-O events. Now let's move along to the consideration of what might have triggered these amazing changes.

Causes: The Oceanic Conveyor Belt

The basic idea came to me in 1984 while I was listening to a lecture given by my longtime friend, Hans Oeschger, at the University of Bern in Switzerland. He pointed out that the Greenland ice core record suggests that the Earth's climate was jumping back and forth from one state of operation to another, staying in one for a millennium or so, and then jumping to the other. I was captivated by Hans' thought and began to ponder what these states might be. It soon dawned on me that they could be related to a change in a major feature of the ocean's thermohaline circulation system which I subsequently termed its conveyor belt. Now that it's famous, people refer to it as Broecker's Conveyor Belt. But it's only fair to say that I have a colleague, Arnold Gordon, who thinks it's his conveyor belt rather than mine. But, it doesn't really matter. We both agree that it's an extremely important feature of the Earth's climate system.

My idea can be summarized as follows. As shown in Fig. 2, one of the most prominent features of today's ocean circulation is the strong northward movement of upper waters in the Atlantic. When these waters reach the vicinity of Iceland, they are cooled by the cold winter air that streams off Canada and Greenland. These waters, which arrive at 12 to 13°C, are cooled to 2-4°C. As the Atlantic is a particularly salty ocean, this cooling increases the density of the surface waters to the point where they can sink all the way to the bottom. The majority of this water flows southward and much of it rounds Africa joining the Southern Ocean's circumpolar current.

The importance of this current to climate is the enormous amount of heat it carries. The conveyor's flow is equal to that of 100 Amazon Rivers! It's similar in magnitude to all the planet's rainfall. So if you have three pipes, one carrying North Atlantic deep water, one carrying all the rain falling on the Earth, and one carrying 100 Amazon Rivers, the outflow from these pipes would be about the same. The amount of heat carried by the conveyor's northward flowing upper limb and released to the atmosphere is equal to about 25% of the solar energy reaching the surface of the Atlantic north of the Straits of Gibraltar.

I had known about this because my career has had a dual aspect. One part of it involved a study of the ocean's deep circulation using radiocarbon and other tracers. The focus was to try to understand how rapidly fossil fuel CO_2 would be absorbed into the ocean. The other involved studies of paleoclimate. I was captivated by the observation that each of the major 100,000-year duration glacial cycles that have hounded us during the last million years came to a catastrophic close. So in 1984, I realized that I could merge these two studies and ask the question, "What would happen if this major current were to be shut off or turned down?" Any such modification would certainly make a major change in the climate of the northern Atlantic region. At my prodding, modelers launched computer simulations of this phenomenon and quickly showed that were the input of warm water to the northern Atlantic to be cut, the mean annual temperature of the lands around the North Atlantic basin would drop by 5° to 10°C. These climate changes would be felt in Newfoundland and Greenland and would penetrate well into northern Europe. However, the models suggested that this cooling would not extend across America to the Santa Barbara basin nor would it extend to the tropics. It certainly would not impact New Zealand.

In addition, ocean modelers followed up on the early work of Henry Stommel (1962) who first demonstrated from a theoretical point of view that the ocean must have several distinct modes of operation. Employing a variety of simulations, they demonstrated that because of the very great sensitivity of deep-water formation to the input of fresh water in polar regions, the ocean could circulate in quite different ways. As rain water contains no salt, its addition lowers the density of surface waters. Further, at high latitudes rainfall and continental runoff exceed evaporation. Because of this, the distribution of places where deep waters can and cannot be generated is sensitive to the pattern of fresh water delivery. So this new class of models verified what Stommel had predicted; indeed their model oceans could make dramatic jumps from one way of operating to another. And in so doing, the amount of heat delivered to the northern Atlantic region greatly changed. But while changes in the conveyor provide a likely explanation for the Greenland ice core record, in no case does any joint ocean-atmosphere model produce the far-field impacts displayed in the paleoclimate record.

Causes: Is Water Vapor up to the Task?

Now we must turn to a more speculative realm because explaining the global extent of these changes is something that we're a long way from accomplishing. An important piece of information in this regard is the state of the Earth's system during the extreme cold millennia of glacial times. At these times, all of Canada and a major portion of the northeastern and midwestern U.S. was covered by a huge ice sheet. Mountains everywhere on Earth experienced a snowline descent of about one kilometer. Geomorphologists have traversed the globe comparing the elevation of the present-day mountain snowlines with those for the last glaciation (reconstructed from geomorphic features). Figure 3 shows the results of such investigations along the American Cordillera. Everywhere from 40°S to 40°N, snowlines descended about one kilometer! Because of this, the southern Andes and New Zealand's South Island, which now have very small glaciers, had quite large ones.

What this tells us is that somehow the Earth got itself into a much colder condition during glacial periods. To my way of thinking, no one has adequately explained how the Earth could ever have accomplished this. We now have new evidence from glacial-age corals (Guilderson et al., 1994) and from glacial-age ground waters (Stute et al., 1995) that the tropics may have been as much as 5°C colder during glacial times. How could the Earth have changed its climate so much in the absence of any strong external forcing?

When I consider the mountain glacier record together with the isotope record obtained for glacial-age ice from six kilometers' elevation on Andean Huascarán (Thompson et al., 1995), I'm forced to the conclusion that the water vapor content of our atmosphere must have been much lower during glacial time. Hence, either the processes which deliver or those which remove water vapor from our atmosphere must have been different during glacial time. But this reduction is something that no model of the atmosphere has yet to accomplish. In fact, these models are powerless to produce the large global changes that the paleo records prove to have taken place. You might ask why water vapor. The answer is that water vapor is the atmosphere's most powerful greenhouse gas. If you wanted to cool the planet by 5°C and could by magic alter the water vapor content of the atmosphere, a 30% decrease would do the job. In fact, the major debate that rages among atmospheric scientists regarding the magnitude of the coming greenhouse warming hinges on what's referred to as the water vapor feedback. If the water vapor in the atmosphere were to remain exactly the same as it is now, then a doubling of CO_2 would heat the planet only about 1.2°C. However, when CO_2 is doubled in these models, their atmosphere holds more water vapor, enhancing the warming to 3.5°C ± 1.5°C. A 3.5°C warming would certainly cause major problems for agriculture, especially where conducted in continental interiors. The debate concerns whether the models change the water vapor in the same way that it will change as CO_2 rises in the real world.

My speculation (see Fig. 4) is that despite the fact that the primary climate impacts of the change in the deep ocean circulation are restricted to the northern Atlantic basin, somehow, as a result, the water vapor budget for the atmosphere must have been altered. Water vapor is supplied to the atmosphere primarily in the tropics by plumes of air which ascend to the upper troposphere along the inter-tropical convergence zone. So if one is to invoke a change in the atmosphere's water vapor inventory, one has got to look to the tropics, and, in particular, to the western tropical Pacific. It is here where convective activity feeds a major portion of water vapor into the air.

If so, the change in the deep circulation must have repercussions throughout the upper ocean. As evidence that this is the case, we have the Santa Barbara basin record, which indicates that, at least in the North Pacific, there must have been a major change in the style of upper ocean ventilation. This is important because the energy budget of the tropical atmosphere is influenced by the upwelling along the equator of cold ocean water. This cold water is fed in from the thermoclines to the North and South Pacific. The now famous El Niño cycle involves a turning on and off of this upwelling. This cycle has a strong impact on today's global climate. So I think that somehow the change in the vigor of upper ocean circulation must have altered the strength of upwelling into the equatorial region and, in turn, the delivery of water vapor into the atmosphere.

This aspect of my argument is particularly speculative, because we don't know how it could happen. But to produce large and abrupt changes in global climate that are symmetrical around the equator, it seems to me that only atmosphere's water vapor is up to the task. If water vapor were the villain, then we must look to the equatorial systems for the key. My guess is that changes in the fresh-water budget of the surface North Atlantic threw the ocean's deep circulation into chaos. If it reformed in another mode of operation, in so doing, it triggered changes in other parts of the ocean and in turn in the delivery of water vapor to the tropical atmosphere. As this source maintains the atmosphere's water vapor inventory all the way out to 35 degrees either side of the equator, the impact would be global. This way of looking at it suggests that we might be able to find in the paleo climatic record a causal chain from northern Atlantic to equatorial Pacific and hence to the atmosphere. But I doubt it. The links likely act so fast that, within the accuracy of even the most precise of our dating tools, all the changes occurred at one time. We have already seen that Greenland air temperature, Asian dust production and global methane production changed together. Some of the impacts may take longer than others to reach a new steady state but all were likely initiated during a time interval of no more than a few decades.

Our Future

So the question naturally arises as to whether this finding about past climates has any implications for the future. First, in this connection, let's review some things that most of you already know about. Human population is rising at a rate of 1.75% each year. If continued, by the middle of the next century, population would reach the staggering level of 14 billion. Fortunately, most predictions suggest that declining birth rates will ease somewhat this potentially desperate situation. But regardless, we're headed for an excess of 10 billion people (see Fig. 5). At just the time we expect sizable greenhouse warming impacts, we're going to have at least five billion more people to feed than we do now. That is an enormous challenge, even in the absence of a climate change.

The amount of CO_2 we produce depends on two things. How many people there are and how much energy they use. Keep in mind that the poorer people on the Earth are going to seek a better standard of living and that's going to require more energy. Almost all of our energy now comes from burning fossil fuels, and hence involves adding CO_2 to the atmosphere. The hope at the Rio Conference was that the production rate of CO_2 could be held to its 1990 level, but the production rate has already risen well above that level. Some politicians believe that this Rio goal is achievable, but I don't. So I suspect that we are going to generate seven or more gigatons of carbon as CO_2 every year. At this rate, the CO_2 content of the atmosphere will rise at the rate of about two parts per million (ppm) per year (see Fig. 6).

So the CO_2 content of the atmosphere will continue to go up. How far depends on a lot of things. Maybe there will be a miracle and we'll find some alternate energy source which is socially acceptable and economically fundable. But, there's little doubt in my mind that late in the next century, the CO_2 content of our atmosphere will reach twice its pre-industrial value of 280 ppm (i.e., 560 ppm). And before we're free from our dependence on fossil fuels, we'll probably drive the CO_2 content up to 700 ppm or more.

For this rise in CO_2, models yield a range of global warmings. The reason is that they differ in the extents of water vapor feedback. As already stated, were there no such feedback, the warming would only be about 1.2°C and would not produce much difficulty. But if the extent of warming for doubled CO_2 were 3, 4, or 5°C, as some models predict, then I think everybody would agree there is going to be big trouble.

What I've injected into this already complicated situation is the realization that in the past climate changes haven't come gradually. Whatever pushed the Earth's climate didn't lead to smooth changes, but rather to jumps from one state of operation to another. So the question naturally arises, what is the probability that through adding CO_2 we will cause the climate system to jump to one of its alternate modes of operation? I contend that since we can't yet reproduce any of these jumps in computer simulations, we don't really know how many modes of operations the Earth has, and we certainly don't have any idea what it might take to push the system from one mode to another. We do know, however, that a substantial warming would surely reduce the density of polar surface water and thereby tend to cut off deep ventilation. So we're entering dangerous territory. It seems to me that we're provoking an ornery beast. Our climate system has proven that it can do very strange things. And since we've only recently become aware of this capability, there's nothing concrete that we can say as far as the implications of this capability to the future. But this discovery certainly gives us even more reason to be prudent about what we do. We must prepare for the future by learning more about our wicked climate system and we must create the wherewithal to respond if the CO_2-induced climate changes are large or worse yet if they come abruptly, changing agricultural conditions across the entire planet. We have to think all this through. Even if there is only a 1% probability that such a change might occur during the next 100 years, its impact would be sufficiently catastrophic that it warrants a lot of preparation.

In conclusion, my lifetime study of the Earth's climate system has humbled me. I'm convinced that we have greatly underestimated the complexity of this system. The importance of obscure phenomena ranging from those which control the size of raindrops to those which control the amount of water pouring into the deep sea from the shelves of the Antarctic continent make reliable modeling very difficult, if not impossible. If we're going to predict the future, we have to achieve a much greater understanding of these small-scale processes which add together to generate big-scale effects.

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Profile

M.S. Swaminathan Research Foundation (MSSRF)

Chairman: Dr. M.S. Swaminathan

History

1988 MSSRF was established by M.S. Swaminathan, the Chairman of MSSRF

1990 MSSRF established the Centre for Research on Sustainable Agricultural and Rural Development as its core organization

The M.S. Swaminathan Research Foundation was founded in 1988 with the goal of promoting research and activism devoted to furthering rural and agricultural development by environmentally sustainable and socially equitable means. The founder and chairman of the organization is Dr. M.S. Swaminathan, the recipient of the 1986 Albert Einstein World Science Award and the first World Food Prize, in 1987.

One of the research foundation's major achievements has been the study and conservation of coastal ecosystems, particularly mangrove wetlands. Based on its research into vegetation, soil salinity, and other aspects of mangrove habitats, the research foundation has taken steps to restore degraded wetlands while promoting sustainable agroforestry and aquaculture.

The M.S. Swaminathan Research Foundation conducts a community biodiversity program to rescue endangered plant species from extinction. Furthermore, it engages in a wide variety of research projects, including one aimed at identifying microorganisms that serve as bioindicators of ecosystem health, and another concerned with conserving the genetic diversity of plant species.

Another program of the Foundation is the creation of an economic stake in conservation by linking conservation and commercialization in a symbiotic manner. The Foundation has established a Technical Resource Centre for the implementation of the equity provisions of the Convention on Biological Diversity. The Foundation is also the coordinating center for the Asian Technology Network sponsored by UNESCO.

In addition, the research foundation promotes the bio-village model of sustainable rural development in India, the People's Republic of China, and Southeast Asia. By helping to conserve the natural environment of developing countries while supporting the economic viability of rural communities, the M.S. Swaminathan Research Foundation is playing an important role in the search for solutions to global environmental problems.

Essay

Sustainable Development—Five Years after Rio

Dr. M. S. Swaminathan
Chairman, MSSRF

February 1997

The UN Conference on Environment Development (UNCED) held at Rio de Janeiro in June 1992 was designed to bring about a global transition from unsustainable to sustainable development. The conference was not an exercise in empty rhetoric. On the contrary, it came to grips with the most serious challenges facing humankind in restoring harmony between economic development and conservation of nature and natural resources, and in ensuring opportunities for sustainable food and livelihood security for generations yet to be born. Agenda 21, the global conventions on climate and biodiversity and the forestry principles adopted at UNCED provide a blueprint for sustainable development. Five years after Rio, we have to admit that the enthusiasm witnessed there in adopting these commitments has yet to be translated in an adequate measure into political and public action.

The change in course recommended by business and industry at Rio for making good business and good ecology two sides of the same coin has also yet to take place on a significant scale. There has, however, been great progress in the greening of the media and judiciary. Leading organizations, like the Asian Productivity Organization, are doing their best to promote green productivity movements. The Blue Planet Prize instituted by the Asahi Glass Foundation on the occasion of UNCED and similar initiatives have helped to keep environmental issues high in the public mind and political agenda.

Japanese institutions and individuals have been at the forefront of human efforts in promoting the coexistence of the Earth, economy, and humankind. The Tokyo Declaration, adopted on February 20, 1997, at a symposium organized on the occasion of the Mainichi newspaper's 125th anniversary, articulates current concerns and enunciates a global plan of action, including the establishment of a Council on the Earth's Environment by the United Nations to perform functions in the area of ecological security—similar to that of the Security Council in the field of peace among nations. Japanese scientists and technologists have also shown ways of achieving very considerable reductions in CO_2 and SO_2 emissions. Scientific work is responding to societal concerns. The Japanese example needs to be replicated worldwide speedily.

The conventions on biological diversity and climate adopted at Rio and ratified subsequently by most member nations of the United Nations are slowly being given operational content at the meetings of the Conference on Parties (COP). COP-3, which relates to the Framework Convention on Climate Change and is scheduled to take place in Kyoto, Japan, in

December 1997, should establish clear numerical goals to reduce emissions of greenhouse gases. Developing countries have to be helped in meeting their energy needs through environmentally benign technologies.

We are now in the second age of massive species extinction. The Convention on Biological Diversity (CBD) shows the way for the conservation of biodiversity and its sustainable and equitable utilization. Today, the primary conservers of the Earth, mostly rural and tribal women in developing countries, are poor, while those who utilize the genetic material conserved and enhanced by them, through biotechnology and breeding enterprises, are rich. We should end this sad irony soon by implementing the equity provisions of the CBD in both letter and spirit. At our Foundation in Madras, India, we have established the Technical Resource Centre for the implementation of the equity provisions of the CBD and we will be happy to assist all committed to recognizing and rewarding the invaluable contributions of the primary conservers of the Earth. Such a step will help to create an economic stake in conservation.

Conservation and commercialization can become mutually reinforcing and not remain antagonistic as at present if principles of ecology, equity, and ethics are integrated with those of economics in the exploitation of natural resources. Business and industry should work together with nongovernmental organizations engaged in such a mission. The Iwokrama International Rainforest Center, established in Guyana in about 400,000 ha. (about a million acres) of prime forest land—generously made available by the government and people of Guyana for developing and demonstrating methods of sustainable management of tropical rain forests—is currently engaged in developing ground rules for the involvement of the private sector in equity-based bioprospecting and sustainable forest management. There is an urgent need for adequate international donor support for this unique adventure in harmonizing the goals of conservation and commercialization in the management of rain forests. Tropical rain forests provide the home for over 60% of the world's species and saving them is a priority task for humankind.

The term green revolution, coined by Dr. William Gaud of the United States in 1968, has come to be associated not only with higher production through enhanced productivity, but also with several negative ecological and social consequences. There is also frequent reference to the fatigue of the green revolution, which relates to stagnation in yield levels and the ever-increasing requirements for nutrients to produce the same yields as in the early 1970s. Experts like Lester Brown have been warning about an impending food crisis for several reasons:

- increasing population;
- increasing purchasing power, leading to the consumption of more animal products;
- increasing damage to the ecological foundations of agriculture;
- declining per capita availability of land and water;
- the absence of technologies that can further enhance the yield potential of major crops.

Should we therefore assume that as we enter a new millennium, we will not have the benefit of new technologies that can help our farmers to produce more food and other agricultural commodities from less land and water?

I believe we are now in a position to launch an "evergreen revolution" that will help to increase yield, income, and livelihood per unit of land and water—if we bring about a paradigm shift in our agricultural research and development strategies. The green revolution was triggered by the genetic manipulation of yield in crops like rice, wheat, and maize. The evergreen revolution will be triggered by farming systems that can help to produce more from the available land, water, and labor resources without either ecological or social harm. Thus, progress can be achieved if we shift our mind-set from a commodity-centered approach to one based on entire cropping or farming systems. This does not mean that we should decelerate our efforts in the area of crop improvement research. But such research should be tailored to enhancing the performance and productivity of an entire production system. The transition from the fatigue of the green revolution to an evergreen revolution involves a shift from a crop-centered to a systems-based approach to technological development and dissemination.

Scientists now have unique opportunities for designing farming systems that will achieve the triple goals of more food, more income, and more livelihood per hectare of land, provided we harness the tools of ecotechnologies: biotechnology, informatics (including GIS mapping), space technology, and renewable energy technologies (solar, wind, biomass, and biogas), as well as management and marketing techniques. We can enter a millennium of hope if we abandon the old concept of a crop-centered green revolution and substitute it with an evergreen revolution, centered on farming systems and frontier technologies.

Industrialized countries are responsible for many of the global environmental problems, such as potential changes in temperature, precipitation, sea level, and incidence of ultraviolet-B radiation. While further agricultural intensification in industrialized countries will be ecologically disastrous, the failure to achieve agricultural intensification and diversification in developing countries, where farming provides most of the jobs, will be socially disastrous. This is because agriculture—including crop and animal husbandry, forestry and agroforestry, fisheries and agrofisheries—provides livelihoods for over 70% of the population in developing countries. The smaller the farm, the greater is the need for higher marketable surplus for increasing income. Eleven million new livelihoods will have to be created every year in India and these have to come largely from the farm and nonfarm rural industries sectors. Importing food and other agricultural commodities will have the same impact as importing unemployment.

In the ultimate analysis, the environmental and intergenerational equity goals of UNCED can be achieved only if material affluence is tempered by spiritual influence. Both unsustainable lifestyles and unacceptable poverty should become features of the past in the coming millennium. This can be achieved if the rich of the world regard themselves as trustees of their surplus wealth and use it for public good. The following principles, enunciated by Mahatma Gandhi over 60 years ago, illuminate the path to sustainable societies and nations.

- Nature provides for everybody's need, but not for everybody's greed.
- We cannot be nonviolent to nature unless the principle of nonviolence becomes central to the ethics of human culture.

Here is the pathway to keep our planet ever blue.

Lecture

Ecotechnology and Sustainable Food Security

Dr. M.S. Swaminathan
Chairman, MSSRF

I. Introduction

Chairman Furumoto, ladies and gentlemen. On behalf of my colleagues, my research center, my wife, and myself, thank you again for this honor and this great opportunity also to meet so many distinguished scientists and experts here this afternoon.

The topic on which I would like to speak, the topic which is consuming a large portion of the resources of our small research center, is ecotechnology and sustainable food security. I would like to define the two terms so that you can understand what I am going to say subsequently. Ecotechnology means at least three E-words: ecology, economics, and equity. Without economic viability, the technology will not take off. Without ecological sustainability, the gains will be very short-lived. And without equity, both in gender and economic terms, we will find that the world will not be a happy place. There will be more and more social disintegration and the rich-poor divide will increase.

So ecotechnologies are those which can combine some of these characteristics, particularly environmental soundness with economic viability. And what little work has been done in the world, both in industry and agriculture, shows that this is quite feasible. In fact, the book produced by the World Business Council during Rio, titled *Changing Course*, has stated that good ecology is also good business today. Conversely, ecologically unsound practices are not good business practices. The Asahi Glass Foundation has shown this with the Blue Planet Prize.

The concept of food security has undergone considerable change in the last 40 or 50 years. In fact, ever since the Food and Agricultural Organization was established in 1945, the problem of global food security has received attention in numerous fora. In the 1940s, 50s, and 60s, the problem of food security was largely considered in the context of food production; the amount of food produced globally at the macro level, and the population and the amount of food required for the population. Then it became clear that this definition was inadequate, because there might be a lot of food in the world but still very many hungry or undernourished people. And therefore the economic dimension of food security—namely, sustainable livelihoods or the purchasing power of the people, the ability to buy food—became very important.

And later it became clear that these two definitions alone, that is, economic access and physical access to food, are not adequate. It is also important to consider other aspects of food, not only calories and proteins, but particularly micronutrients, like iron, zinc, iodine, and Vitamin A; deficiencies of these nutrients lead to what is often called hidden hunger. In fact, according to recent United Nations figures, if about 800 million women, men, and children go to bed hungry tonight, nearly two billion suffer from hidden hunger, or hunger for micronutrients. Vitamin A deficiency, for example, causes blindness in children.

And the third dimension of food security relates to environmental parameters, particularly hygiene, environmental hygiene, safe and clean drinking water. Because it is not enough if we take food. The biological retention and absorption of food are equally important for a healthy body. And therefore the food security concept has undergone considerable evolution in the last 40 or 50 years.

The science academies of the world have been meeting in order to articulate the scientific viewpoint on matters which are largely discussed at the political level at these summits. For example, before Cairo the U.S. National Academy of Sciences, the Royal Society of London, and the Indian National Science Academy all got together and looked at population in the context of science and technology. And before the World Food Summit starting on November 13, 1996, in Rome, we thought it was equally important that the scientific academies get together. They got together at our Foundation in Madras in July 1996. At this Science Academies Summit, food security was defined as follows:

- that every individual has the physical, economic, social, and environmental access to a balanced diet that includes the necessary macro- and micronutrients, safe drinking water, sanitation, environmental hygiene, primary healthcare, and education so as to lead a healthy and productive life.
- that food originates from efficient and environmentally benign production technologies that conserve and enhance the natural resource base of crops, animal husbandry, forestry, and inland and marine fisheries.

II. The 20th century: a balance sheet

As we approach a new century we can look back and draw a balance sheet of our achievements and failures. Spectacular progress in science and technology ranks first among our major accomplishments. Recent advances in biotechnology and genetic engineering, space technology, information technology, and new materials have opened up uncommon opportunities for a world where every individual can lead a healthy and productive life. The spread of democratic systems of governance, the breakdown of skin color-based apartheid and the advent of the information age have created the sociopolitical substrate essential for integrating the principles of intra- and intergenerational equity in public policy. The power of a right blend of technology and public policy is strikingly evident from the progress made in recent decades to keep the growth rate in food production above the rate of growth in population, thereby ensuring that the Malthusian prediction of population overtaking our ability to produce adequate food does not come true (International Commission on Peace and Food, 1994).

While the positive achievements are many and make us proud of the power of the human intellect, we will be entering the new millennium with some of the greatest social and scientific challenges humankind has ever faced. Several of these challenges have been articulated with great clarity in the Human Development Reports of the United Nations Development Programme (UNDP) of recent years.

Environmental degradation and increasing economic and gender inequality are among the most serious problems we face today. The rich-poor divide is increasing at an alarming rate. The pattern of development adopted by rich societies is leading to jobless economic growth, pollution, and potential changes in climate. Unsustainable lifestyles on the part of the rich billion and unacceptable poverty on the part of another billion coexist. The absence of an educational and health environment, which is conducive to every child achieving his/her innate genetic potential for physical and mental development, leads to the spread of poverty in capability. UNDP has proposed indicators for measuring both human development and human capability (UNDP, 1996).

The U.S. National Academy of Sciences, the Royal Society of London, the Indian National Science Academy and 55 other scientific bodies in a statement made in 1993 pointed out "stress on the environment is the product of four interacting factors: population growth, consumption habits, technology and social organization." Concurrent attention is needed on all these four factors to promote sustainable development and sustainable societies. The report, "Sustainable America," indicates what an affluent society should do (The Presidents' Council on Sustainable Development, 1996). In poor nations, the social sustainability of the development process is as important as ecological and economic sustainability. Also, if the current pace of damage to the ecological foundations essential for sustainable advances in biological productivity—namely, land, water, flora, fauna, forests, oceans, and the atmosphere—continues, sustainable food and nutrition security cannot be achieved. Therefore, as we approach the new millennium, we need a broader concept of sustainability which encompasses environmental, economic, and social parameters. Among social factors, gross economic and gender inequity needs priority attention. If such a paradigm shift in developmental thinking and pathways does not occur, the successes achieved in the 20th century in abolishing skin color-based apartheid, in conquering space and in splicing genes will be overshadowed by the spread of technological and economic apartheid. If these forms of apartheid are allowed to grow and spread, social disintegration and ecological genocide will be the result.

III. Ecotechnology: the emerging solution

Technologies rooted in the principles of ecology, economics, and equity are now referred to as ecotechnologies. The United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Cousteau Foundation established by Commandant Jacques Cousteau are promoting ecotechnology networks in different parts of the world. The M.S. Swaminathan Research Foundation (MSSRF) at Madras is the coordinating center for the Asian Ecotechnology Network. A major purpose of this Network is the creation of ecojobs, which are economically viable, environmentally benign, and socially equitable. A multimedia database on opportunities for ecojobs is being developed, since the dissemination of information on ecojobs is essential for creating opportunities for sustainable livelihoods in rural and urban areas.

The most serious manifestation of poverty is hunger. It is now recognized that endemic hunger is largely the result of inadequate livelihood opportunities which in turn lead to inadequate purchasing power. Hidden hunger results from both micronutrient deficiencies and poor environmental hygiene, which impair the biological absorption and retention of food.

During the next three decades, population is expected to increase by another 2.5 billion people. Food requirements will grow due to increases in both population and per capita purchasing power. World grain production has grown from 631 million metric tons in 1950 to nearly 1,900 million tons in 1995. Such a phenomenal growth has had its environmental costs in terms of soil degradation, aquifer depletion, genetic erosion, and pesticide pollution. This is why we have to produce more in the coming decades but produce it differently. To achieve such a shift, the following basic ground rules must be followed in technology development and dissemination as well as in public policy.

First, production advances must be based on linking the ecological security of an area with the livelihood security of the people in a symbiotic manner.

Second, steps must be taken to create widespread awareness of the human and animal population supporting capacity of different ecosystems. Sustainable systems of management of soil, water, biodiversity, and forests should be internalized in rural societies.

Third, since the poor remain poor, because they have no productive assets and there is no value to their time, asset creation and value addition to time should receive high priority in poverty-alleviation programs. Women belonging to the economically underprivileged sections of the society, in particular, are often overworked and underpaid. What they need is a reduction in the number of hours of work and an increase in the economic value of each hour of work. This will call for massive efforts in information and skill empowerment of the poor, particularly women. The emerging technologies are largely knowledge-intensive and hence the transfer of knowledge and market-driven skills can become the most powerful instrument for fighting poverty and deprivation. Modern information technology affords opportunities for reaching the unreached and thereby achieving a learning revolution within a short span of time.

Four, equal attention is needed to the problems of the rural and urban poor. Lack of livelihood opportunities in rural areas leads to the proliferation of urban slums. Damage to common property resources in villages results in the growth of environmental refugees (Myers and Kent, 1995). Since in many developing countries agriculture—including crop and animal husbandry, forestry, fisheries, and agro-processing—provides most of the jobs and income in rural areas, the triple challenge of producing more food, income, and jobs from diminishing per capita land, water, and nonrenewable energy sources can be met only through agricultural intensification, diversification, and value addition. Integrated, intensive farming systems, which are ecologically sustainable, are needed for this purpose.

Finally, an evergreen revolution of the kind described above can be imparted a self-propelling and self-replicating momentum only if it is based on the self-mobilization of the people. In all externally funded and introduced development projects, there should be a built-in withdrawal strategy, so that the program does not collapse when the external inputs are withdrawn.

IV. Meeting the multidimensional challenges: the response of the M.S. Swaminathan Research Foundation

The responses being developed and field tested by MSSRF to identify implementable approaches at the micro- and policy levels to meet the challenges outlined earlier are briefly described below:

A. Linking the ecological security of an area with the livelihood security of the local community: creating an economic stake in conservation

The community biodiversity program of MSSRF illustrates how such mutually beneficial linkages can be fostered in biodiversity-rich areas. It is a sad fact that the tribal and rural families who have conserved and enhanced biodiversity remain poor, while those who are utilizing the products of their efforts become rich. When the conservers have no social or economic stake in conservation, denudation of natural ecosystems becomes more rapid. MSSRF has adopted a three-pronged strategy for creating an economic stake in biodiversity conservation.

First, a transparent and implementable methodology has been developed for incorporating *sui generis* systems of plant variety protection procedures for recognizing and rewarding informal innovations in genetic resource conservation and enhancement (Swaminathan, 1996).

Second, a symbiotic social contract between commercial companies and tribal and rural families is being fostered for the purpose of promoting the cultivation by local communities of genetic material of interest to the companies on the basis of buy-back arrangements. Such a linkage will prevent the primary material being unsustainably exploited.

Third, local women and men are trained in the compilation of biodiversity inventories and in bio-monitoring, so that they themselves become custodians of their intellectual property. Such trained women and men constitute an Agrobiodiversity Conservation Corps and will be able to help their respective communities to deal with issues such as "prior informed consent" in the use of genetic resources.

For assisting the community biodiversity movement, MSSRF has established a Technical Resource Centre for the implementation of the equity provisions of the Convention on Biological Diversity. Since this is the first Technical Resource Centre of its kind in the world, the six major components of the Centre are described below.

i. Chronicling the contributions of tribal and rural families to the conservation and enhancement of agrobiodiversity through primary data collection in the states of Tamil Nadu, Kerala, Andhra Pradesh, and Orissa as well as in the Lakshadweep and Great Nicobar group of islands.
ii. Organization of an Agrobiodiversity Conservation Corps of young tribal and rural women and men, who have a social stake in living in their respective villages and who, with appropriate training, can undertake tasks such as compilation of local biodiversity inventories, revitalization of the in situ genetic conservation traditions of their respective communities, monitoring of ecosystem health with the help of appropriate bio-indicators and restoration of degraded sacred groves. The members of the corps will be able to assist their respective communities in dealing with the "prior informed consent" provision of the Convention on Biological Diversity in the use of genetic resources.
iii. Development of multimedia databases documenting the contributions of tribal and rural families in the conservation and improvement of agrobiodiversity, for the purpose of

enabling them to secure their entitlements from National and Global Community Gene Funds.

iv. Maintenance of a Community Gene Bank and Herbarium A Community Gene Bank with facilities for medium-term storage has been established to conserve farmer-preserved and -developed seeds from the tribal areas of South India. The material will be cataloged and linked to the Technical Resource Centre database. The Herbarium serves as a reference center for the identification of landraces, traditional cultivars and medicinal plants conserved by tribal and rural families.

v. Revitalization of genetic conservation traditions of tribal and rural families through social recognition of their contributions and the creation of an economic stake in conservation. For this purpose, replicable models of private-sector engagement in contract cultivation by tribal and rural families of plants of commercial value are being developed.

vi. Legal advice cell to make available to tribal and rural families appropriate legal advice in matters relating to intellectual property rights and plant variety protection.

B. The population-supporting capacity of ecosystems: local-level socio-demographic charter

In order to help internalize an understanding of the vital need to restrict population growth within the supporting capacity of land, water, forests, and the other components of the ecosystem, training modules have been developed to enable the female and male members of village-level democratic institutions to prepare socio-demographic charters for their respective villages. A gender code is an important component of the charter. Such socio-demographic charters will help local communities to view population issues in the context of social development and to ensure that children are born for happiness and not just for existence.

C. Information and skill empowerment

For this purpose, the concept of Information Villages has been developed (Swaminathan, 1993). Trained rural women and men will operate Information Shops where generic information on the meteorological, management, and marketing factors relevant to rural livelihoods will be converted into location-specific information. Trained farm women and men themselves become trainers. The computerized extension system adopted in the Information Shops also helps to sensitize local families on their entitlements from government and other programs. Information technologies provide considerable opportunities for value-added jobs in rural areas. While new technologies are important, folk media are often even more effective in reaching the unreached. Hence, folk plays and folk art and theater are fully mobilized for achieving information empowerment. For ensuring the success of information empowerment programs, the information disseminated should be demand-driven and should be locale-specific.

D. Agricultural intensification, diversification and value-addition

This is achieved through participatory research with farm families. Ecotechnologies like integrated pest management and integrated nutrient supply are used. Ecotechnology development involves the blending of the best in frontier technologies with traditional wisdom and practices.

Modern science and the ecological prudence of the past can thus be combined (Swaminathan, 1994).

Ecotechnologies are also practiced in aquaculture. Integrated agriculture and aquaculture techniques enhance both farm income and the nutrition security of the household. Whole villages are being enabled to adopt such integrated, intensive farming systems (IIFS). Since this approach is essential for meeting the triple goals of more food, income, and jobs from the available land and water resources, the seven basic principles guiding the IIFS movement are described below:

i. Soil health care

   This is fundamental to sustainable intensification. IIFS fosters the inclusion of stem-nodulating legumes like *Sesbania rostrata*, incorporation of *Azolla*, blue-green algae and other sources of symbiotic and non-symbiotic nitrogen fixation and promotion of cereal-legume rotation in the farming system. In addition, vermiculture composting and organic recycling constitute essential components of IIFS. IIFS farmers are trained to maintain a Soil Health Card to monitor the impact of farming systems on the physical, chemical, and microbiological components of soil fertility.

ii. Water harvesting and management

   IIFS farm families include in their agronomic practices measures to harvest and conserve rainwater, so that it can be used in a conjuctive manner with other sources of water. Where water is the major constraint, technologies which can help to optimize income and jobs from every liter of water are chosen and adopted. Maximum emphasis is placed on on-farm water use efficiency and on the use of techniques such as drip irrigation, which help to optimize the benefits from the available water.

iii. Crop and pest management

   Integrated Nutrient Supply (INS) and Integrated Pest Management (IPM) systems form important components of IIFS. The precise composition of the INS and IPM systems will depend on the components of a farming system as well as on the agro-ecological and soil conditions of the area. Computer-aided extension systems will provide farm families with timely and precise information on all aspects of land, water, pest, and post-harvest management.

iv. Energy management

   Energy is an important and essential input. Besides the energy-efficient systems of land, water, and pest management described earlier, every effort will be made to harness biogas, biomass, solar, and wind energies to the maximum extent possible. Solar and wind energy will be used in hybrid combinations with biogas for farm activities like pumping water and drying grains and other agricultural produce.

v. Post-harvest management

   IIFS farmers will not only adopt the best available threshing, storage, and processing measures, but will also try to produce value-added products from every part of the plant or animal. Post-harvest technology assumes particular importance in the case of perishable commodities like fruits, vegetable, milk, meat, egg, fish, and other animal products and processed food. A mismatch between production and post-harvest technologies adversely affects both producers and consumers. Growing urbanization leads to a diversification of food habits. Therefore there will be increasing demand for animal products like milk, cheese, eggs, and processed food. Agro-processing industries can be promoted on the basis of an assessment of consumer demand. Such food processing industries should be promoted in villages in order to increase employment opportunities for rural youth. In addition, they can help to mitigate micronutrient deficiencies in the diet.

Investment in sanitary and phytosanitary measures is important for providing quality food for both domestic consumers and export. To assist the spread of IIFS, government should make a major investment in storage, roads, transportation, and on sanitary and phytosanitary measures.

vi. Choice of the crop and animal components of farming systems

In IIFS, it is important to give very careful consideration to the composition of the farming system. Soil conditions, water availability, agro-climatic features, home needs, and above all, marketing opportunities will have to determine the choice of crops, farm animals, and aquaculture systems. Small and large ruminants will have a particular advantage among farm animals since they can live largely on crop biomass. Backyard poultry farming can help to provide supplementary income and nutrition.

vii. Information, skill, organization and management empowerment

IIFS is based on the principle of precision farming. Hence, for its success, the IIFS system needs a meaningful and effective information and skill empowerment system. Decentralized production systems will have to be supported by a few key centralized services, such as the supply of credit, seeds, biopesticides, and animal disease diagnostics. Ideally, an Information Shop will have to be set up by trained local youth in order to give farm families timely information on their entitlements as well as on meteorological, management, and marketing factors. Organization and management are key elements and, depending on the area and farming system, steps will have to be taken to provide to small producers the advantages of scale in processing and marketing.

IIFS is best developed through participatory research between scientists and farm families. This will help to ensure economic viability, environmental sustainability, and social and gender equity in IIFS villages. The starting point is to learn from families who have already developed successful IIFS procedures.

It should be emphasized that IIFS will succeed only if it is a human-centered rather than a mere technology-driven program. The essence of IIFS is the symbiotic partnership between farming families and their natural resource endowments of land, water, forests, flora, fauna and sunlight. Without appropriate public policy support in areas like land reform, security of tenure, credit supply, rural infrastructure, input and output pricing and marketing, small farm families will find it difficult to adopt IIFS.

E. Increasing farm and nonfarm employment

The biovillage program addresses three key areas—preventing resource degradation, improvement of crop and animal productivity, and alleviation of poverty. The biovillage program in progress in villages in the Pondicherry area of India places equal emphasis on off-farm livelihood opportunities and on-farm jobs. This program avoids a patronage approach to poverty alleviation.

It regards the poor as producers and innovators and helps to build their assets through value addition to time and labor. The basic approach is on asset building and sustainable human development leading to the growth of entrepreneurship.

The programs are designed on a pro-nature, pro-poor, and pro-women foundation. By placing emphasis on the strengthening of the livelihood security of the poor, the biovillage model of sustainable development revolves around the welfare of the economically and socially underprivileged.

It is thus a human-centered pattern of development. The enterprises chosen are based on marketing opportunities. The technological and skill empowerment of the poor is the major approach. Because of the market-driven nature of the enterprises, the economic viability of the biovillage approach is assured. Production and post-harvest technologies and farm and non-farm occupations are brought together in a manner that benefits both producers and consumers.

Biovillages around biosphere reserves would help in providing alternative sources of meeting the day-to-day needs for food, fuel, fodder, and other commodities of the families living near such biodiversity-rich areas. Also, biovillages near urban areas help to link the rural producer and the urban consumer in a mutually beneficial partnership. By producing the processed and semiprocessed food products needed in urban areas in the villages around towns and cities, the need for the rural poor to migrate to urban centers for livelihood opportunities is minimized. Also, food processing can be used as a method of providing the needed micronutrients by including millets and grain legumes in the food.

F. <u>The final milestone: a hunger-free world</u>

The above represent some of the approaches adopted at MSSRF to overcome the challenges of jobless growth, feminization of poverty and environmental degradation. The Tamil Nadu Government has recently decided to introduce a Hunger-Free Area Programme to end poverty-induced hunger in association with MSSRF.

Studies at MSSRF have shown that by adding a horizontal dimension to numerous vertically structured programs and by promoting a coalition of all concerned with ending hunger and deprivation, it is now possible to provide opportunities for a healthy and productive life for all.

The problem of food and nutrition security at the level of the individual has to be viewed in three dimensions. First, inadequate purchasing power leads to calorie-protein undernourishment. Second, the lack of the needed quantity and variety of micronutrients and vitamins in the diet leads to several nutritional disorders, including blindness caused by Vitamin A deficiency. This kind of problem is referred to as "hidden hunger," a problem which today affects more than two billion people in the world. Third, lack of environmental hygiene and sanitation leads to a low biological absorption and retention of food, due to intestinal infection and diarrhea. Thus, both food and nonfood factors assume importance in determining the nutrition security of an individual. Concurrent action at all these levels is necessary in a Hunger-Free Area Programme.

Development that is not equitable will not be sustainable in the long term. A hunger-free and more equitable world is essential for our planet remaining ever blue. Given appropriate ecotechnologies and public policies, there are now great opportunities for a better common present and future for all members of the human family. It is to serve this cause that MSSRF will utilize the funds associated with the Blue Planet Prize.

V. Research strategies and results: some examples

A. Coastal systems research: conservation and development of mangrove ecosystems

The area of the Pichavaram mangrove forest, degraded over a period of 100 years, was estimated using remote sensing techniques. Between 1897 and 1994 nearly 63% of the mangrove forest cover became degraded.

Year	**Area**	**Source**
1897	700 ha	Forest Department, Government of Tamil Nadu
1994	260 ha	Remote Sensing Unit, MSSRF

A major cause for such large-scale degradation of the Pichavaram mangroves has been identified. Structural changes in the mangrove wetlands, particularly development of trough-shaped topography, due to reduced inflow of fresh water and the consequent impoundment of tidal water, increase soil and ground water salinity. High salinity was responsible for nearly 70% of the degradation. Grazing and felling for fuel were responsible for only 30% of the degradation.

Techniques to restore the areas degraded due to the formation of trough-shaped topography were developed and successfully demonstrated. The government management agency is now adopting this technique for the restoration of another 100 ha of the degraded area of the Pichavaram mangroves.

To arrest degradation due to felling and grazing, an agroforestry system was introduced. Techniques of growing fodder species in the coconut and casuarina groves, the major agriculture plantations in the coastal areas, were successfully demonstrated with the participation of the local communities. These techniques are now being replicated by the farmers themselves.

On the basis of the experience gained, a project titled "Coastal Wetlands: Mangrove Conservation and Management" is being implemented in the major mangrove wetlands of the entire east coast of India. This project is supported by the India-Canada Environment Facility. The goal of this project is to enhance the capacity of the local communities, voluntary organizations, grass-roots democratic institutions and government agencies to conserve, restore, and sustain mangrove wetlands through participatory research, training, and extension.

B. Biodiversity and biotechnology

i. Conservation

The main objective of this program is Conservation of Endangered Plant Species. For this purpose eight key areas ("hot spots") have been identified from the southern Western Ghats, such as Siruvani Hills, Gudalur Gene Pool Reserve, Kulathupuzha R.F. Kakki Hills, and Sholayar.

The activities of this program include systematic collection, detailed description, *ex situ* preservation of sample materials, storage of voucher specimens (herbarium) and micropropagation.

The results of the study are as follows:

- Collection of over 120 rare or threatened flowering plants including 20 species which are listed in various Red Data Books.
- Assessment of the status and distribution pattern of these plants by using IUCN-revised threat status guidelines.
- Development of a database for the rare and threatened plants collected (Rare Angiosperm Plant Database)
- A herbarium for threatened/rare, medicinal, and traditional crop varieties.
- Two species have been rediscovered (*Sageraea grandiflora* and *Euonymous serratifolius*) and a new range of distribution for the species *Crotalaria speciosa, Hydnocarpus pendule*, and *Piper barberi* has been recorded.
- Successful micropropagation of five endangered plant species collected.

During 1995, the Siruvani Hills have been periodically surveyed for monitoring of population dynamism of selected endangered plant species (e.g., *Vateria macrocarps, Indigofera constricta, Anaphyllum wightii, Crotalaria speciosa,* and *Anectochilus elatior*).

ii. Value addition through information

In southern India certain interesting characteristics accompany the tribal utilization of plants. Often, many plants are used for a single purpose although other parts of the plants may have potential utility values. For example, the following plants are used almost exclusively for their edible fruits and seeds: *Bredelia retusa, Canthium dicoccum, Ficus racemosa, Madhuca longifolia var lalifolia, Palaqium ellipticum, Polyalthia cerasoides, Scnlieichera oleosa,* and *Xylia xylocarpa*. These plants are not used for construction or making agricultural implements or other such uses.

Tribal use of plants is also characterized by diversity of choice. The majority of the human population depends on fewer than 100 plant species for most of their requirements. In contrast, the tribal people living in southern India use several hundred. Thus a variety of plants are used as edible greens: *Amaranthus spp., Cansjeera rheedii, Colocasia esculenta, Lycianthes laevis, Mukia maderaspatana, Talinum cuneifolium,* and *Trichosanthes nervifolia*. Similarly, fruits of many plant species, to name a few like *Carissa carandas, Cordia obliqua,* and *Memecylon edule*, are eaten by them.

This approach not only increases the choice of plants and hence the nutritional value but also prevents overexploitation of any single or a few species. Ethnobotanical studies conducted in Tamil Nadu by MSSRF reveal that the tribal communities use 223 plant species for various purposes, of which 88 plants are of edible value, 149 plants are used for medicinal purposes, and 53 plants for other material purposes.

Tribal communities show prudence and ecological wisdom in resource utilization.

The Kadars of Tamil Nadu, for example, select only mature plants of the yam *Dioscorea* for harvesting the tubers. They first examine the vine and choose only those whose leaves are yellow, which is an indication of maturity. Tubers of young green vines are never dug out. After harvesting the mature yams they cut off the upper portion of the tuber along with the vine and replant it in the pit. They cover the pit with loose soil to allow the tuber to regrow for whoever may harvest it in the future. The community as a whole shares the harvest thus avoiding overexploitation. Part of the collection is stored for consumption during the off-season.

Medicinal properties of plants have been recognized and utilized by tribal communities traditionally over thousands of years. Knowledge of some common local medicinal plants is available from all members of the community. However, the elderly members possess a great deal of knowledge of medicinal plants as well as of medicines for curing certain life-threatening diseases. Tribal people use plants exclusively or in combination. Some plants may be used for different disorders: for example, *Calotropis gigantea* is used as vermicide and for chest pain, *Centella asiatica* for gynecological problems and for jaundice, *Dodonaea viscosa* for headache, stomachache and piles, *Wrightia tinctoria* for treating mumps and as a lactagogue. In certain cases a combination of different plants may be used in the treatment of specific diseases. For example, *Albizia lebbec* together with *Cassia fistula* and *Euphorbia hirta* is used for urinary disorder. *Capparis zeylanica* with *Toddalia asiatica* is used for venereal disease. Each tribe has its own method of collecting the plants as well as preparation of medicines. Dosage and duration of medication depend on the age of the patient and the intensity of disease. Tribal people collect the plant part used for medicine at a particular time, such as either before flowering or fruiting, or in a particular season.

iii. Traditional agricultural practices of tribal communities

Tribal communities like Irulas, Malayalis, and Muthuvas inhabiting Tamil Nadu have been cultivating the traditional cultivars such as paddy, millets, pulses, and vegetable crops. Nearly 58 traditional cultivars have so far been identified from the tribal communities, of which 21 are minor millets. Their subsistence lifestyle, local dietary habits and dependence on rain-fed irrigation have influenced them to cultivate and conserve the traditional cultivars or landraces. Many crops such as *Panicum miliaceum*, *Echinocloa colona*, *Paspalum scrobiculatum*, and *Setaria italica* are now cultivated and conserved only by the tribal people in many parts of southern India. By selecting and conserving the seeds from one season to the next, they have been able to sustain the cultivation. For example, healthy cobs are left in the field so as to allow them to dry for several days to make sure that no moisture is left in the seeds. The selection of large and healthy seeds and the selection based on the color of the seeds (e.g., in the case of Castor seeds) have also helped them to ensure seed viability. The tribal communities prefer to continue the cultivation of traditional cultivars as these are ecologically adapted and economically viable. The landraces and traditional cultivars cultivated by tribal families are also drought- and disease-tolerant.

Community cooperation and participation prevailing particularly in the Malayali tribal community have helped them in conserving the traditional landraces. The practice is such that every family in the community will contribute a stipulated amount of their harvest to the community granary maintained and managed by the chieftain of the hamlet. During important occasions like marriages, social events, and festivals and also when someone needs them for regular consumption, grains can be borrowed on loan and later returned. This system has enabled the tribe to conserve the seed material even if the produce in a particular season is less or if the grains stored for domestic consumption are exhausted.

Seed material for sowing and the grains for consumption are preserved in traditional granaries. These granaries are made of bamboo and coated with red soil. The roof is conical and is thatched with local grass. There is a free flow of air in the granaries, which may be one of the reasons why the seeds remain viable until used the next time. The seeds are also stored in earthen pots covered with a cotton cloth. This indigenous practice has saved many varieties of cereals, millets, and legumes in Tamil Nadu. This practice has enabled the community to maintain, preserve, and conserve the genetic strains. Leaves of plants such as neem and *Vitex* are used in the granaries as insect and pest repellents.

iv. Patterns of distribution of vertebrate diversity on the Great Nicobar biosphere reserve

The Great Nicobar Island has been declared one of the eight biosphere reserves in India. This island is unique for its endemic species. The MSSRF has taken up a three-year project in which the island is being mapped systematically for distribution and diversity of vertebrates. This is being attempted for the first time in the history of the island.

More than 100 species of vertebrates including birds, mammals, reptiles, amphibians, and inland fish have been identified and their distributions recorded. The island has been divided into 55 grids of five kilometers by five kilometers. Apart from the distribution of vertebrates, the human impacts on each of these grids have been assessed. The various human impacts have been scored appropriately. Simultaneously, the availability of well-preserved habitats has also been assessed. Using this information, about 50% of the island

Conservation Value Based on Habitat Information

					4		
					7		
2					5		
7					7		
	7			7	9		
		2			9		
	4			1	0		
				–2			
				1			
		3	1				
		3	1				

that has already been mapped has been assigned conservation value. The numbers given in the following grid map of the Great Nicobar Island suggest that the grids marked 9 are the best in terms of habitat quality and those marked 0 and -2 are the most disturbed areas on the island. It is envisaged that the information on vertebrate distribution and diversity will be superimposed on this map for better understanding of ecological problems the island is facing and for recommendation of management of the biosphere reserve.

v. Biodiversity and molecular biology

Genetic characterization of a species and assessment of degree of polymorphism within it are the basic prelude to any meaningful conservation program. Conventional genetic studies are difficult in mangroves, and so far no worthwhile studies have been carried out on this group of plant species. Published accounts are few and largely restricted to some stray reports on chromosome analysis and enzyme studies. Based on the available information, it is not possible to partition with a reasonable degree of confidence the observed phenotypic variability in mangroves into environmental and heritable components. In view of the delay and difficulties in conventional genetic analysis, studies on genetic polymorphism, relationship, and diversity are being undertaken using molecular markers. Unlike morphological markers, molecular markers are not prone to environmental fluctuations. In addition, studies on identification, characterization, and isolation of novel genetic traits such as salt tolerance from this group of species are under way.

Objectives

- Documentation of chromosome number and preparation of chromosome atlas for Indian mangrove species
- Analysis and assessment of the nature and extent of intra-site and inter-population genetic diversity in different mangrove species
- Development of species-specific genomic clones
- Establishment of genetic relationships and evolutionary trends among mangrove species
- Identification and isolation of novel genetic combinations (e.g., salt-tolerant genes)

Mangrove species offer several physical and systemic constraints. They often occupy inaccessible habitats and there have been no proper identification criteria for different species/varieties. The leaf and other tissues are rich in phenolics and other secondary metabolites and mucilages.

Results obtained so far

- Somatic chromosome numbers have been determined for 12 mangrove species.
- Species-specific protocols for isolation of enzyme-digestible genomic DNA have been established for about 25 species.
- Genetic relationships have been established among species belonging to 21 mangrove genera using molecular markers.
- Genetic polymorphism at inter- and intra-population level have been worked out in 12

mangrove species. The number of populations for each species ranged from six to 12.
- More than 1,500 low-copy genomic clones have been identified from the partial genomic library of six mangrove species.
- Di-, tri- and tetra-nucleotide repeat positive clones have been identified and sequenced to design species-specific flanking primers.
- A cDNA library is being constructed for isolation of salt-tolerant genes. Variation in protein expression in response to stress is being studied.

Conclusions

- All the analyzed mangrove species are high polyploids.
- The observed genetic variability is species-specific and largely influenced by the climatic and other physical characteristics of the ecological zones the species inhabit.
- Polymorphism is independent of the morphological variability and the sexual nature of the species.
- Molecular markers could be used for delineating the species at population level.
- The 21 mangrove genera could be grouped into five distinct clusters. Within each cluster, the species show overall genetic similarity.
- It would be possible to use molecular markers for species identification.
- A few clones identified from the genomic libraries show the presence of sequences homologous to stress-induced gene sequences.

Species under study

The mangrove species under study include *Avicennia marina, A. officinalis, Acanthus ilicifolius, Rhizophora apiculata, R. mucronata, R. lamarckii, Excoecaria agallocha, Lumnitzera racemosa, Ceriops decandra, Bruguiera cylindrica, Aegiceras corniculatum, Kandelia candel*, etc. All these species were assessed for their intra-specific genetic polymorphism. In all these species, protocols for quality and enzyme-digestible DNA were developed. The presence of large amounts of secondary metabolites like phenolics, mucilage, and latex in these species complicate the process of purification as they co-precipitate along with the nucleic acids during the isolation steps. However, species-specific protocols developed gave pure DNA/RNA preparations in these plants.

Both the random amplified polymorphic DNA (RAPD) and restriction fragment length polymorphism (RFLP) fingerprinting pattern are being used to assess the intra- and inter-specific and intra- and inter-population genetic polymorphism in individual species. In all these species distinct populations were selected both from the eastern and western coasts of peninsular India. The samples collected from these locations were used for isolation of DNA and further subjected to RAPD and RFLP analysis. About 10-15 plants from each population were used to account for the intra-population variations. Detailed RAPD analyses were carried out on all the important genera using as many as 10 populations in each species depending on their distribution and occurrence.

Our results show that the variation in the polymerase chain reaction (PCR)-based RAPD profile with the use of both 10 random primers and simple sequence repeats is species-specific and largely influenced by the climatic conditions and ecological zones the species occupy. The variations observed are independent of the morphological variability and also the reproductive nature of the plants. Population-specific markers have been developed in *Acanthus ilicifolius*. RFLP analyses were carried out in these species using the genomic clones developed from the respective mangrove species. The results also reflect a similar trend as observed in the case of RAPD analysis.

The genetic relationship between 20 mangrove species has been established using molecular markers through PCR-generated random amplified polymorphic DNA profiling. In all, 10 random primers were used that produced 172 amplification products. The presence and absence of these markers in 20 mangrove and one nonmangrove species (*Rauvolfia tetraphilla*) were scored and used for construction of a dendrogram for depicting the genomic relationship between the species. These species formed five distinct clusters with the nonmangrove species forming a separate operational taxonomic unit (OTU). This is the first time a genetic relationship between a number of mangrove species has been established using molecular markers. All 20 species taken up in this study include all the species in the Pichavaram mangrove forest, Tamil Nadu.

Species-specific clones/ DNA probes from mangroves

PCR-generated clones and clones developed by genomic libraries were used for our RFLP studies. Genomic clones have been developed in the following mangrove species: *Acanthus ilicifolius, Avicennia spp., Excoecaria agallocha, Rhizophora spp., Ceriops decandra, Bruguiera cylindrica,* and *Lumnitzera racemosa*. The 1,000-plus clones including all the above species are being maintained in pUC plasmids and selected clones are being used for our RFLP experiments as DNA probes.

By screening all the clones using different microsatellites few DNA repeat-positive clones were obtained. Characterization of these positives by double-stranded DNA sequencing is under way in order to synthesize species-specific flanking primers for these repeat sequences to analyze polymorphism profiles in these species more precisely.

Screening of the available clones and also generation of cDNA clones by cDNA library construction is under way in order to isolate salt-stress induced genes. Promising clones shall be transferred to other plant species by transformation to look for its functional capability to provide enhanced osmotic stress tolerance in the target plant.

C. Internalizing the gender dimension in development programs

The basic aim of the program area is advocacy to bring gender-related concerns to the forefront of the development process. Advocacy is at two levels—both to influence the policy process and to create a climate of supportive public opinion. These findings are applicable to networking, training, and development of instructional materials.

The major research studies in the last two years relate to gender roles—one on the child care needs of women working in the unorganized sector, and the other on women's multiple roles and the management of breast-feeding. We have brought to light important findings about the way women handle their multiple roles, and these are being actively used for promoting woman-friendly policies in the economic arena, as well as for creating awareness among different interest groups like employers, professionals, and the media.

Communication draws on a wide range of approaches, from traditional folk performing arts which are utilized to convey messages of sustainable development, to contemporary theater forms which are being used in an interactive and participatory way to give expression to women's own voices through their own cultural idioms, as well as to explore the attitudes and values underlying social problems related to gender inequity and to bring these into the arena of public discussion.

Electronic media (radio, TV, and video) are used both for training and dissemination of ideas as well as for "social marketing," that is, through repeated short messages on gender-related themes. Journalism, literature, databases, documentation, and campaign materials are also utilized to create wide awareness on these issues, while training materials are produced to help the groups engaged in public education.

D. Information empowerment

The Informatics Centre in the Foundation has twin goals:

1. It functions as a service unit for all the laboratories and field units of the Foundation by offering high-quality and consistent access to electronic databases and to the Internet.
2. It conducts design jobs that aim at use of modern information technology as a key technology in promoting learning and information dissemination for sustainable agricultural and rural development and sustainable management of biological diversity.

The Informatics Centre was established in December 1993 with a collection of personal computers, scanners, back-up devices, and printers with a rudimentary e-mail connection to Internet. It had a collection of CD-ROM databases published by CAB International. In the three years since inauguration, the hardware has been reasonably updated to keep pace with the very rapid changes and developments resulting in the availability of a good laboratory for design of multimedia, navigable databases. The CD-ROM collection is considered to be the largest in this country in the broad area of agricultural sciences, covering nearly 3.7 million records. Since late 1995, full access to the Internet has been provided on a dial-up basis. In terms of coverage, the CD-ROM facility is used by hundreds of visiting scientists from all over India every year.

The multimedia databases include the following:

- Mangrove Ecosystems Information Service (MEIS)
- Farmers' Rights Information Service (FRIS)
- Ecological Farm Families of India

The MEIS is a collection of databases with global coverage: its experts' directory covers 62 countries, its bibliography covers the period starting from 1975 (complementing the UNESCO bibliography, 1600-1975), its sites and resources databases cover 22 sites in nine countries in detail and 1,100 sites in 42 countries in a limited fashion. More than 700 visuals are available in a separate database.

The FRIS is a pilot multimedia database which functions as a component of the Technical Resource Centre for implementing the equity provisions of the Convention on

Biological Diversity. The FRIS contains data in various forms (audio/video, text/numbers, photos/diagrams) relating to tribal lifestyles, use of plant genetic resources, sacred groves, rare angiosperms, and related details for the states of Tamil Nadu and Orissa. Besides original data, the FRIS provides detailed pointers to secondary information that is known but scattered.

The multimedia database on ecological farm families covers both technological and economic details of farms that use ecological techniques with high biological productivity. This contains animations of technical processes.

E. Looking ahead

The above are some aspects of the studies in progress. They all have the goal of harnessing modern science for solving problems of importance to improve the quality of life of the socially and economically underprivileged sections of rural and tribal communities. The challenges are great but so are the opportunities for meaningful work. Whatever work has been done so far indicates that we now have uncommon opportunities for a better common present.

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