Kates, R. W., 2001. "Sustainability Transition: Human-Environment Relationship," In N. J. Smelser and Paul B. Baltes (editors) International Encyclopedia of the Social and Behavioral Sciences, Pergamon, pp. 15325-15329.

Lin D Y, Wei J L, Ying Z 1998 Accelerated failure time models for counting processes. *Biometrika* **85**: 608–18

Mantel N 1966 Evaluation of survival data and two new rank order statistics arising in its consideration. *Cancer and Chemotherapy Reports* **50**: 163–70

Nielsen G G, Gill R D, Andersen P K, Sorensen T I A 1992 A counting process approach to maximum likelihood estimation in frailty models. *Scand Journal of Statistics* **19**: 25–43

Oakes D 1989 Bivariate survival models induced by frailties. *Journal of the American Statistical Association* **84**: 487–93

Oakes D 2000 Survival analysis. *Journal of the American Statistical Association* **95**: 282–5

Parzen M I, Wei L J, Ying Z 1994 A resampling method based on pivotal estimating functions. *Biometrika* **68**: 373–9

Pepe M S, Cai J 1993 Some graphical displays and marginal regression analysis for recurrent failure times and time dependent covariates. *Journal of the American Statistical Association* **88**: 811–20

Peto R, Peto J 1972 Asymptotically efficient rank invariant test procedures (with discussion). *Journal of the Royal Statistical Society Series A*, **135**: 185–206

Prentice R L 1978 Linear rank tests with right censored data. *Biometrika* **65**: 167–79

Prentice R L, Cai J 1992 Covariance and survivor function estimation using censored multivariate failure time data. *Biometrika* **79**: 495–512

Prentice R L, Hsu L 1997 Regression on hazard ratios and cross ratios in multivariate failure time analysis. *Biometrika* **84**: 349–63

Prentice R L, Williams B J, Peterson A V 1981 On the regression analysis of multivariate failure time data. *Biometrika* **68**: 373–9

Robins J M, Tsiatis A A 1992 Semiparametric estimation of an accelerated failure time model with time-dependent covariates. *Biometrika* **79**: 311–9

Samuelsen S O 1997 A pseudolikelihood approach to analysis of nested case-control studies. *Biometrika* **84**: 379–84

Therneau T, Grambsch P 2000 *Modeling Survival Data: Extending the Cox Model*. Springer, New York

Van der Laan M J 1996 Efficient estimation in the bivariate censoring model and repairing NPMLE. *Annals of Statistics* **24**: 596–627

Wei I J, Lin D Y, Weissfeld L 1989 Regression analysis of multivariate incomplete failure time data by modeling marginal distributions. *Journal of American Statistical Association* **84**: 1065–73

Ying Z 1993 A large sample study of rank estimation for censored regression data. *Annals of Statistics* **21**: 76–99

R. L. Prentice and J. D. Kalbfleisch

Sustainability Transition: Human–Environment Relationship

The reconciliation of society's human developmental goals with the planet's environmental limits over the long term is the foundation of an idea known as sustainable development. This idea emerged in the early 1980s from scientific perspectives on the interdependence of society and environment, but even as it garnered increasing political attention and acceptance around the world, its scientific base weakened. The decade of the 1990s has seen an effort to re-engage the scientific community around the requirements for a sustainability transition. Beyond its commonplace meaning as a transition towards a state of sustainable development, a sustainability transition was studied as a series of interlinked transitions, as a process of adaptive management and social learning, and as a set of indicators and future scenarios.

1. *Sustainable Development*

The origins of sustainable development can be traced back through the 1980 World Conservation Strategy and the 1972 Stockholm Conference on the Human Environment to the early days of the international conservation movement (O'Riordan 1988, Adams 1990). But the contemporary linking of environment and development is little more than a decade old, stemming from *Our Common Future*, the 1987 report of the World Commission on Environment and Development (also known as the Brundtland Commission). The Commission defined sustainable development as the ability of humanity 'to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). An extraordinarily diverse set of groups and institutions have taken this widely accepted statement of sustainable development and projected upon it their own hopes and aspirations. While sharing a common concern for the fate of the earth, proponents of sustainable development differ in what they think is to be sustained, what is to be developed, how each is related to the other, and for how long a time.

The most common view as to what is to be sustained are planetary life-support systems, particularly those supporting human life (Kates 1994). These systems include natural resources as well as environments that provide aesthetics, recreation, pollution absorption and cleansing, and other ecosystem services (Daily 1997). Contrasting this anthropocentric view is one of sustaining nature itself in all its biodiversity and assemblages of life forms. These ought to be sustained, not only for their utilitarian service to humans, but because of the moral obligations of humanity arising either as 'stewardship'—still acknowledging the primacy of humans—or as a form of 'natural rights' in which earth and its other living things have equal claims for existence and sustenance. Also for some, cultural diversity is seen as the counterpoint to biological diversity, and various communities that include distinctive cultures, particular groups of people, and specific places need to be sustained.

The most common view of what is to be developed is the economy that provides employment, needed income, desired consumption, and the means for investment in physical and human capital, as well as environmental maintenance and restoration. An alternative emphasis is on people-centered human development which focuses on the quantity of life, as seen in the survival of children and their increased life expectancy, and the quality of life through education and equal opportunity. Finally, some discussions of what is to be developed emphasizes society itself, addressing the well-being and security of national states, regions and institutions.

The relationship between what is to be sustained and what is to be developed also differ. Some conceptual statements, provide equal emphasis for both; others, while paying homage to sustainable development, seem to be saying 'sustain only,' 'develop mostly,' or 'sustain or develop subject to some minimal constraint on the other.' Similarly the implied time horizons for sustainable development differ. There is universal acceptance that such time horizons are intergenerational, but these then range between a single generation of 25 years, several generations, or as an unstated, but implicit, forever. Each of these time periods present very different prospects and challenges for sustainable development. Over the space of a single generation, almost any development appears sustainable; over an infinite forever none does.

At the century's end, the difficulties of actually delivering on these diverse hopes that people around the world have attached to the idea of sustainable development had become increasingly evident. In part, these difficulties reflected political problems, grounded in questions of financial resources, equity and the competition of other issues for the attention of decision-makers. In part, they reflect the differing views about what should be developed, what should be sustained and over what period. Additionally, however, the political impetus that carried the idea of sustainable development so far and so quickly in public forums has also increasingly distanced it from its scientific and technological base.

2. *Interlinked Transitions*

Thus during the 1990s several groups of scientists sought to reinvigorate their historic connection with the concept of sustainable development by focusing not on the larger concept, with all its actual and implied diverse meanings, but on a sustainability transition. The interest in transitions arose in part from the widespread perception that the continuation of current trends in both environment and development would not provide for the desired state of sustainable development. To the extent that transitions represent breaks in such trends, there was growing interest in identifying the needed or desired transitions in the relationships between society and environment.

There was also widespread interest in the post-Cold War world in the nature of transitions themselves. Attention was focused on the economic transition from state to market control and on the civil society transition from single-party, military or state-run institutions to multiparty politics and a rich mix of nongovernmental institutions (Mathews 1997). Earlier transitions had also been identified, such as that in settlement patterns from rural to urban; in agricultural productivity from increases in production derived from additional land to increases derived from greater yields; and in health from early death by infectious diseases to late death by cancer, heart attack, and stroke. For the environment, significant transitions were seen for biogeochemical cycles in a shift from dominance by natural processes to dominance by human releases; for specific pollutants from increasing to decreasing rates of emissions; and for land cover in temperate zones a change from deforestation to reforestation (Turner et al. 1990).

But the greatest interest lay in the successful confirmation of the 'demographic transition'—the change in population regimes from ones of high birth and death rates, to ones of low birth and death rates. The demographic transition appeared credible because it met scientific criteria: it was partly supported by theory, matched well the data and had predictive power (Kates 1996). It was also seen as both needed and desired because of the widespread consensus that rapidly growing population made more difficult human development, while further stressing the natural systems that needed to be sustained.

On a global scale, at the century's end, the transition in birth rates was more than halfway towards birth stability, the 2.1 births required to achieve eventual zero population growth, with an average of less than three children for each woman of reproductive age, compared with five at the post World War II peak of population growth. The death transition was even more advanced, with life expectancy at birth having increased from 40 years to 66 years, about three-quarters of the way to the stabilizing stage of the transition, when life expectancy is likely to reach 75 years. Mid-range projections (in 1998) foresaw further slowing of population growth rates with 8.9 billion people in the world by 2050 and stabilizing to 9.5 billion by the century's end (United Nations 1999).

Thus, in the first major conceptualization of the 'sustainability transition' Speth (1992) set forth a series of five inter-linked transitions (demographic, technological, economic, social and institutional) as collective requirements for a sustainability transition. In addition to the desired demographic transition, Speth saw the need for a transition towards technologies that were environmentally benign and reduced sharply the consumption of natural resources, and the generation of waste and pollutants. For the economy, the desired transition was towards one in which prices reflected their full environmental costs. A social transition would move towards a fairer sharing of economic and environmental benefits both within and between countries. All of these transitions required a fifth: a transition in the institutional arrangements between governments, businesses and people that would be less regulation-driven and more incentive-led, less confrontational and more collaborative. To these five, Gell-Mann (1994) further suggested an ideological transition towards a sense of solidarity that can encompass both the whole of humanity and the other organisms of the biosphere and an informational transition that integrates disciplinary knowledge and disseminates it across the society.

Together, Speth and Gell-Mann present these transitions as requirements for a more sustainable world: if each individual transition is completed successfully the result would constitute a sustainability transition. And all of these transitions may be underway as there are some trends in each of the desired directions. To investigate this concept they organized a major, albeit uncompleted, research effort known as the '2050' project (World Resources Institute, Brookings Institutions, Santa Fe Institute) that sought to track these transitions and understand their interactions.

3. *Adaptive Management and Social Learning*

A different approach was adopted by the National Academy of Sciences (USA) Board on Sustainable Development (1999). It too adopted a two generation, to the year 2050, time horizon. But in *Our Common Journey: A Transition Toward Sustainability*, the Board doubted that any specific set of trends or transitions constituted necessary or sufficient conditions for sustainability. It argued that the pathway to a sustainability transition could not be mapped in advance. Instead, it would have to be navigated adaptively through trial and error, and conscious policy experimentation (Holling 1978, Lee 1993) and a process of social learning (Social Learning Group 2001) as well other devices such as indicators and scenarios (described below).

What could be selected were goals for a sustainability transition. In the Board's judgment, the primary goals of a transition toward sustainability over the next two generations should be to meet the needs of a much larger but stabilizing human population, to sustain the life-support systems of the planet, and to reduce hunger and poverty substantially. Specific targets for these goals for human well-being and environmental preservation have been defined over the past few decades through extensive processes of international political debate and intergovernmental action.

In the area of human needs, internationally agreed-on targets exist for providing food and nutrition, nurturing children, finding shelter and providing an education, although not for finding employment. Thus, there is an implicit hierarchy of needs that favors children and people in disasters, and favors feeding and nurturing first, followed by education, housing and employment.

Compared with targets for meeting human needs, quantitative targets for preserving life-support systems are fewer, more modest and more contested. Global targets now exist for ozone-depleting substances and greenhouse gases, and regional targets exist for some air pollutants. Absolute prohibitions (zero targets) exist for ocean dumping of radioactive wastes and some toxics, for the taking and/or sale of a few large mammals (whales, elephants and seals), migratory birds when breeding or endangered, and certain regional fishing stocks. Water, land resources and ecosystems such as arid lands and forests have, at best, qualitative targets to achieve sustainable management or restoration. International standards exist for many toxic materials, organic pollutants and heavy metals that threaten human health, but not for ecosystem health.

A major action and research agenda was developed in *Our Common Journey* based on both current scientific understanding and the requirements of an emerging sustainability science. For the core sectoral areas of sustainable development identified more than a decade ago by the Brundtland Commission—human population and well-being, cities, agriculture, energy and materials, and living resources—the Board identified concrete goals and appropriate next steps to accelerate major transitions underway or needed in each sector. To create a research agenda of what might be called 'sustainability science,' the Board would promote the creation of usable knowledge from scientific understanding; would seek to integrate global and local perspectives to shape a 'place-based' understanding of the interactions between environment and society; and initiate focused research programs on a small set of understudied questions that are central to sustainability transition.

4. *Indicators and Scenarios*

The largest scientific effort to date has been the creation of indicators of sustainable development and to use them to track a transition toward sustainability. It sought to make more realistic the diverse meanings of sustainable development by attempting to develop indicators of the different values so implied. A major effort was launched by the Scientific Committee on Problems of the Environment (Moldan et al. 1997) and an important alternative effort by the so-called Balaton Group (Meadows 1998). These scientific efforts complemented similar efforts by various local, national, and international groups to create indicators as ways of expressing desired values for sustainable

Table 1
Sustainable development in the USA: an experimental set of indicators

Economic	**Environmental**	**Social**
Capital assets	Surface-water quality	Population of USA
Labor productivity	Ratio of renewable water supply to withdrawals	Life expectancy at birth
Domestic product	Fisheries utilization	Births to single mothers
Income distribution	Acres of major terrestrial ecosystems	Children living in families with only one parent present
Consumption expenditures per capita	Invasive alien species	Educational achievement rates
Unemployment	Conversion of cropland to other uses	Educational attainment by level
Inflation	Soil-erosion rates	Teacher training level and application of qualifications
Investment in R&D as a percentage of GDP	Timber growth to removals balance	People in census tracts with 40 percent or greater poverty
Federal debt to GDP ratio	Outdoor recreational activities	Crime rate
Energy consumption per capita and per $ of GDP	Contaminants in biota	Participation in the arts and recreation
Materials consumption per capita and per $ of GDP	Quantity of spent nuclear fuel	Contributing time and money to charities
Homeownership rates	Identification and management of superfund sites	
Percentage of households in problem housing	Metropolitan air quality nonattainment	
	Status of stratospheric ozone	
	Greenhouse-gas emissions	
	Greenhouse climate response index	

futures (http:}}iisd1.iisd.ca/measure}compendium.htm and United Nations Commission for Sustainable Development 1996). A set of 40 economic, environmental and social indicators for the USA that use existing data sets are shown in Table 1 (http://www.sdi.gov/reports.htm).

In contrast to indicators such as these that can inform society to what extent progress is being made in a transition toward sustainability, alternative pathways for a transition were explored through long-range development scenarios that reflect the uncertainty about how the global system might unfold. While they are rigorous, reflecting the insights of science and modeling, these scenarios are told in the language of words as well as numbers because assumptions about culture, values, lifestyles, and social institutions require qualitative description. Sets of scenarios were created that reflect current trends and reform proposals, various forms of social and environmental breakdown, and more fundamental transitions or transformations (Raspin et al. 1997, Hammond 1998). Based on these and other data, the National Academy of Science's Board (USA) on Sustainable Development (1999) concluded that:

> Although the future is unknowable … a successful transition toward sustainability is possible over the next two generations. This transition could be achieved without miraculous technologies or drastic transformations of human societies. What will be required, however, are significant advances in basic knowledge, in the social capacity and technological capabilities to utilize it, and in the political will to turn this knowledge and know-how into action.

Bibliography

Adams W M 1990 *Green Development: Environment and Sustainability in the Third World*. Routledge, London

Daily G C 1997 *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington DC

Gell-Mann M 1994 *The Quark and The Jaguar: Adventures in the Simple and Complex*. W. H. Freeman, New York
Hammond A 1998 *Which World? Scenarios for the 21st Century*. Island Press, Washington DC
Holling C S (ed.) 1978 *Adaptive Environmental Assessment and Management*. Wiley, Chichester, UK
Kates R W 1994 Sustaining life on earth. *Scientific American* **271**: 114–22
Kates R W 1996 Population, technology, and the human environment: A thread through time. *Daedalus* **125**(3): 43–71
Lee K N 1993 *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington DC
Mathews J T 1997 Power shift. *Foreign Affairs* **76**: 50–66
Meadows D 1998 *Indicators and Information Systems for Sustainable Development. A report to the Balaton Group*. The Sustainability Institute, Hartland Four Corners, VT
Moldan B, Billharz S, Matravers R (eds.) 1997 *Sustainability Indicators: A Report on the Project on Indicators of Sustainable Development*. Wiley, New York and Chichester, UK
Board on Sustainable Development, National Research Council 1999 *Our Common Journey: A Transition Toward Sustainability*. National Academy Press, Washington, DC
O'Riordan T 1988 The politics of sustainability. In: Turner R K (ed.) *Sustainable Environmental Management: Principles and Practice Boulder*. Westview Press, Boulder, CO
Raskin P, Gallopin G, Gutman P, Hammond A, Swart R 1998 *Bending the Curve: Toward Global Sustainability. A Report of the Global Scenario Group*. Stockholm Environment Institute, Boston
Speth J 1992 The transition to a sustainable society. *Proceedings of the National Academy of Sciences of the United States of America* **89**: 870–72
The Social Learning Group 2001 *Learning to Manage Global Environmental Risks: Vol 1. A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain. Vol 2. A Functional Analysis of Social Responses to Climate Change, Depletion, and Acid Rain*. MIT Press, Cambridge, MA
Turner B II, Clark W, Kates R, Richards J, Mathews J, Meyer W 1990 *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere Over the Past 300 Years*. Cambridge University Press, Cambridge, UK
United Nations 1999 *World Population Prospects: The 1998 Revision*. United Nations Population Division, New York
United Nations Commission for Sustainable Development 1996 *Indicators of Sustainable Development: Framework and Methodologies*. United Nations, New York
World Commission on Environment and Development 1987 *Our Common Future*. Oxford University Press, Oxford, UK

R. W. Kates

Sustainable Development

In the late 1980s, the World Commission on Environment and Development (WCED), otherwise known as the Brundtland Commission, defined sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). Since then, sustainable development has received significant attention from the global community at the local, national, and international level amid concerns about climate change, biodiversity loss, tropical deforestation, and other environmental depletion and degradation problems.

This article discusses briefly the emergence of the concept of sustainable development and provides a broad definition of sustainable development. Two distinct interpretations of sustainable development—*weak* and *strong* sustainability—are compared and contrasted. Recent advances in three areas of the literature that are relevant to understanding sustainable development and to designing appropriate policy responses are examined. These are: ecological functioning and resilience; environmental Kuznets' curve (EKC) and the environment–growth debate; and endogenous growth, technological innovation, and resource dependency. For each area, the basic concept is explained and the implications for sustainable development are discussed. Finally, the policy issues and options for achieving sustainable development are discussed. Four key options are identified: measuring the ecological and economic impact of declining natural resources; improving our estimates of the economic costs of depleting natural capital; establishing appropriate incentives, institutions, and investments for sustainable management of natural capital; and encouraging interdisciplinary collaboration between the relevant social and behavioral sciences undertaking research on sustainable development.

1. *Concept of Sustainable Development*

1.1 *Definition of Sustainable Development*

The broad concept of sustainable development (Pearce and Barbier 2000) encompasses considerations of equity across and within generations, taking a longer-term perspective and accounting for the value of the environment in decision-making (Pearce et al. 1989). As noted by Turner (1997), the concept of sustainable development has been challenged on several grounds: as an oxymoron, as a means of imposing a particular political position, as an approach to divert attention from more pressing socioeconomic problems, and given the history of the human–environment relationship (see *Human–Environment Relationships*). However, sustainable development continues to receive increasing international recognition and it has become a key guiding principle for the global society at the start of the new millennium (National Research Council 1999).

There have been a substantial number of diverse and wide-ranging interpretations of sustainable development, both across and within scientific disciplines. Pearce et al. (1989) provide a collection of

International Encyclopedia of the Social & Behavioral Sciences ISBN: 0-08-043076-7