

SECOND EDITION



# Sustainability Indicators

Measuring the Immeasurable?

Simon Bell & Stephen Morse

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## Measuring the Immeasurable?

Revised edition

*Simon Bell and Stephen Morse*

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# List of Acronyms and Abbreviations

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AMOEBA	general method for ecosystem description and assessment (Dutch)
ASC	Academy for Sustainable Communities
BAAC	Bank for Agriculture and Agricultural Co-operatives (Thailand)
BCCI	Belize Chamber of Commerce and Industry
BITAOC	beneficiaries, implementers, transformation, assumptions (or worldview), owner and constraints
BKK	Badan Kredit Kacamatan (Indonesia)
BOD	biological oxygen demand
BUD	Bank Rakyat Indonesia Unit Desa (Indonesia)
CBA	cost–benefit analysis
CBI	Confederation of British Industry
DDS	Diocesan Development Services (Nigeria)
DfID	Department for International Development (UK)
DPR	driving force, pressure, response
DPSIR	driving force, pressure, state, impact, response
DSD	degree of sustainable development
DSIR	driving force, state, impact, response
DSR	driving force, state, response
ECBA	economic cost–benefit analysis
EDJI	Ecological Dow Jones Index
EEA	European Environment Agency
EKC	Environmental Kuznets Curve
ESI	Environmental Sustainability Index
ESY	ecologically sustainable yield
EU	European Union
FAO	United Nations Food and Agriculture Organization
FS	financial services
FSR	farming systems research
FSR/E	farming systems research and extension
GB	Grameen Bank (Bangladesh)
GCM	global climate model
GIS	geographic information systems

H	Shannon–Wiener Index
IISD	International Institute for Sustainable Development
ISD	indicator for sustainable development
IUCN	World Conservation Union (formerly International Union for the Conservation of Nature)
LF	logical framework/logframe
LISA	low-input sustainable agriculture
LO	learning organization
M & E	monitoring and evaluation
MCA	multi-criteria analysis
MEY	maximum economic sustainable yield
MIS	management information systems
MOV	means of verification
MSY	maximum sustainable yield
N	nitrogen
NEF	New Economics Foundation
NGO	non-governmental organization
ODA	Overseas Development Administration ( <i>now renamed DfID</i> )
OECD	Organisation for Economic Co-operation and Development
OVI	objectively verifiable indicator
P	phosphorous
PDR	pressure, driving force, response
PPP	purchasing power parity
PRA	participatory rural appraisal
PRAM	participatory and reflective analytical mapping
PSI	process SI
RRA	rapid rural appraisal
SCBA	social cost–benefit analysis
SCP	Sustainable Cities Programme
SDI	Subsidy Dependence Index
SI	sustainability indicator
SSA	Systemic Sustainability Analysis
SSI	state SI
SSM	soft systems approach or method
SWOT	strengths, weaknesses, opportunities and threats
TFP	Total Factor Productivity
TUC	Trades Union Congress
UEA	University of East Anglia
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
US	United States
USAID	US Agency for International Development
WCED	World Commission on Environment and Development
WEF	World Economic Forum

WHO	World Health Organization
WHOQOL	World Health Organization Quality of Life
WWF	World Wide Fund for Nature ( <i>formerly</i> World Wildlife Fund)



# Foreword

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As we wrote in the first edition, this book remains the result or outcome of our personal journeys through a great deal of literature and opinion on sustainability – but now this is tempered with experience and reflection. Although both of us have spent many years working in development studies, Steve is an applied biologist with a background in the scientific tradition, whereas Simon defines himself as a systems thinker and action researcher with specific experience in the field of information systems development and computing. Both of us have come by separate routes to the current discussion relating to sustainability; and without being dramatic, this book can still be described as the fruit of a voyage of discovery.

For many years we have both been concerned, but from our different perspectives, with the literature on sustainability and the discussions that this literature has produced. On the one hand, we were worried by the numerous attempts to try and ascribe exact ‘measures’ to sustainability (for instance, sustainability = 42). On the other hand, it appeared that the politicians had created a storm by picking up on the word sustainability, which was intended to be the marker and driving force for the global development effort. Such an emphasis intensified the need for definition and measurement so we could assess our progress towards achievement (or not) of sustainability; and yet the very holistic and anthropocentric essence of sustainability continues to elude attempts at objective analysis and assessment. Managers love to ‘measure’ in order to know that they have managed successfully; but so much of life is immeasurable.

We came to the conclusion separately that in trying to tie down and measure sustainability, surely the civic, academic and developmental communities were engaging in a futile exercise of measuring the immeasurable? Although many have tried to quantify sustainability – with all the jargon and apparent rigour of the objective and reductionist mindset of much of the academic community – when looked at more closely, the approaches do not seem to work or, worse still, we end up measuring things that can be measured and not things that should be measured, if at all possible. Indeed, sustainability is not a ‘thing’ that can be measured, and an element of circularity appears inevitable: sustainability becomes defined by the parameters that can be measured rather than the other way around. *Our key premise is that the*

*approach to measurement is always based on an individual's vision of sustainability, which in turn can be changed depending upon the measurement mindset.*

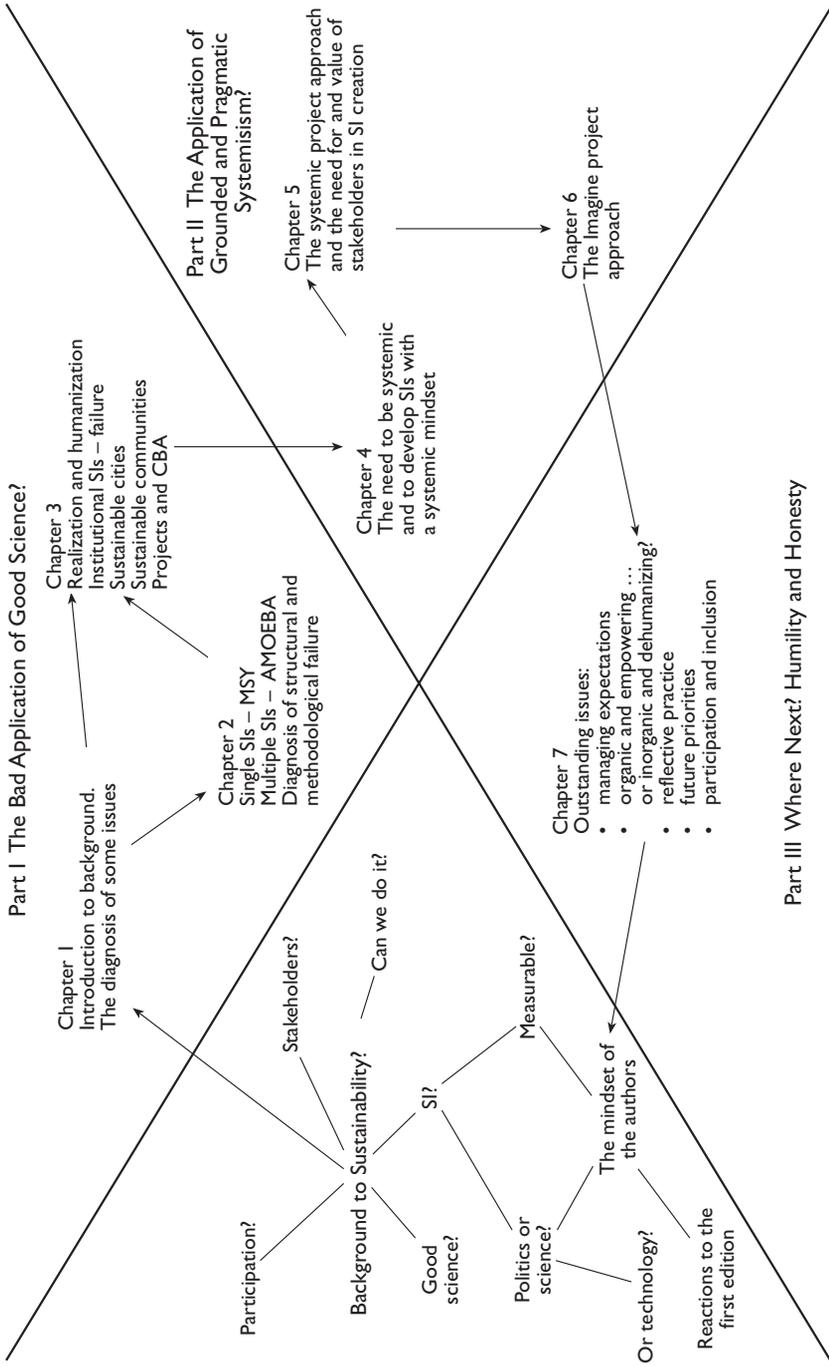
Our concern grew in our analysis of theory and in our own practice as consultants and researchers; despite being told by some colleagues in the early days of writing the first edition that to critically evaluate sustainability indicators was 'off the wall', we decided to both map our understanding of the sustainability indicator debate and to set out what we think might be a more holistic, realistic, participative and systemic approach to gauging sustainability. Now, in this new edition, we can further develop this theme by showing how we have applied the methodology and reflected on our experience.

At the outset, we need to bring to the reader's attention problems concerning the use of the words system and systemic. In the first three chapters of this book, which briefly review the work of academics and practitioners in developing sustainability indicators, the word system is frequently used; however, this is usually in a non-specific everyday sense – the word could be replaced with 'related entities' or even 'things'! In Chapters 4 to 7 we use the words much more specifically and provide definitions of what they mean in precise terms.

This book is both the outcome of a creative endeavour and the reflection of the current debate on sustainability indicators. We offer our thoughts on the discussion so far and suggest ways forward with humility. We both agree that there will be great need for fuller discussion before the issue is in any way resolved, and all we can hope to do is to contribute some personal insights.

The reader will find three distinct sections in the following pages:

- 1 Part I is a literature review on the use of sustainability indicators (SIs) in development. Chapter 1 provides background to the issue of SI development; Chapter 2 focuses on examples of single and multiple SIs; and Chapter 3 looks at institutional SIs and sustainable cities, and introduces the notion of using SIs in projects. Each of these topics can be (and have been) the focus of a book in itself; thus, the aim is to give the reader an overview of issues rather than an exhaustive review of all of the literature.
- 2 Part II sets out an alternative theory: a systemic manner for the development of SIs. In Chapter 4 the theory – Systemic Sustainability Analysis (SSA) – is introduced. SSA provides the underpinning of our thinking with regard to what is required for envisioning sustainability and linking this to indicators. Chapter 5 describes the growth of SI development tools within project contexts and Chapter 6 sets out a grounded version or methodology – Imagine – of the SSA theory to SI development, stressing the essential participative nature of understanding sustainability. There are many ways in which the SSA theory we espouse can be put into practice, and Imagine is presented as an example originally derived for a specific spatial context (coastal zone management), but which adapts to a wide range of circumstances.



**Figure F.1** Overview of the book

- 3 In Part III, Chapter 7 focuses on setting out a number of further questions arising from the discussion and provides an outline of future research interests.

We believe that the discussion that we present here comes together as one overall whole, bringing us back to some of the questions we started with. To assist the reader we have developed a route map of the conversation (see Figure F.1), and we provide step-by-step indicators on this as the conversation develops from chapter to chapter.

The authors encourage readers to engage in the discussion of SIs.

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*January 2008*

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It is impossible to thank all those who have provided contributions and insights to the formulation of this book; but we would like to express our gratitude to all our friends, colleagues and all of the silent recipients of development projects worldwide who have for the last 20 years worked with the authors and helped them in their intellectual, moral and spiritual development.



*Part I*

The Bad Application of  
Good Science?

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# I

# Sustainability and Sustainability Indicators

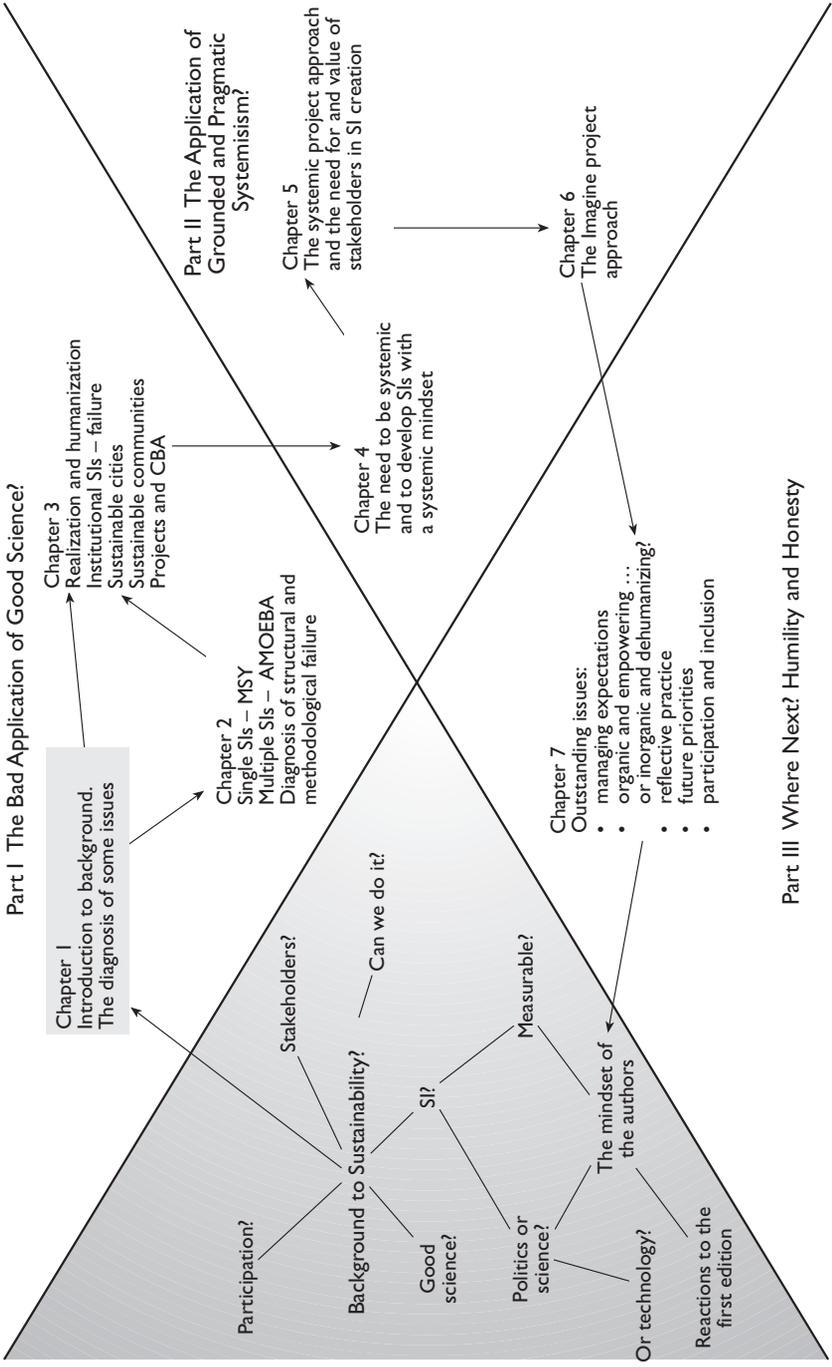
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## Introduction and objectives

Few development interventions or research initiatives these days can successfully attract funding unless the words ‘sustainability’ or ‘sustainable’ appear somewhere in the proposal to the funding agency. Indeed, if one listens to speeches by politicians or reads articles by economists, policy-makers or scientists, the word sustainable appears with remarkable regularity:

*Sustainable development has become the watchword for international aid agencies, the jargon of development planners, the theme of conferences and learned papers, and the slogan of developmental and environmental activists. (Lele, 1991)*

Although some have questioned the motives behind this popularity (Bawden, 1997), there is no doubt that sustainable development is now a very dominant theme. Some even go so far as to say that ‘everyone agrees that sustainability is a good thing’ (Allen and Hoekstra, 1992), although to Fortune and Hughes (1997) ‘it [sustainability] is an empty concept, lacking firm substance and containing embedded ideological positions that are, under the best interpretation, condescending and paternalistic’. The main catalyst for this popularity in recent years, particularly in terms of sustainable development, was the Rio de Janeiro Earth Summit held in 1992. The Rio Summit agreed a set of action points for sustainable development, collectively referred to as Agenda 21 (agenda for the 21st century), and governments that signed up to these have committed themselves to action. In order to help put these points into practice, the summit established a mandate for the United Nations to establish a set of ‘indicators of sustainable development’ that will help to monitor progress. In fact, the idea of using indicators as a means of gauging sustainability has become extremely popular, with many governments and agencies devoting



Part III | Where Next? Humility and Honesty

**Figure C.1** *Chapter 1 in context*

substantial resources to indicator development and testing (Hak et al, 2007). Even the idea of a sustainable city, an apparent contradiction in terms, has become so popular that prizes are now provided for those cities deemed to be the most sustainable, and indicators play a major role in this process. The central idea behind the use of such indicators is very simple, and essentially they are designed to answer the question: ‘How might I know objectively whether things are getting better or getting worse?’ (Lawrence, 1997).

Sustainable development is an example of a paradigm quite distinct from what some see as the contradictory term of sustainable growth (see Daly and Townsend, 1992, for a discussion). Paradigms are important in that they are philosophical and theoretical frameworks within which we derive theories, laws and generalizations. In its broadest sense, the sustainable component of the sustainable development paradigm implies that whatever is done now does not harm future generations – a concept often paraphrased as ‘don’t cheat on your kids’. However, the precise meaning of sustainable, and what it embraces, varies depending upon who is using it and in what context, a critical point which we return to later. For example, can we sustain our environment within sustainable development, yet ‘cheat our kids’ on other aspects, such as decline in economic performance or worsening social conditions? Sustainable development has, indeed, become a quintessential example of practical holism, but at the same time embodies an ultimate practicality since it is literally meaningless unless we can ‘do’ it. As such, it is firmly rooted in the present.

This book is all about the ‘doing’ of sustainable development. In these pages the reader will frequently come across a liberal sprinkling of terms such as ‘achieve’, ‘implement’, ‘practice’, ‘goal’ and ‘do’ with regard to sustainable development. This reflects an important shift away from ‘sustainable’ as an appealing though rhetorical adjective to ‘sustainable’ becoming both a descriptor of something and a target to achieve. Indeed, since it is the ‘sustainable’ part of sustainable development which particularly interests us, we have tended to refer to ‘sustainability’ in a generic sense, and our discussions of sustainability could be employed to anything that has sustainable as an adjective. Therefore, the same broad points we make apply to sustainable agriculture, sustainable coastal zones, sustainable cities, sustainable communities, and sustainable organizations and institutions – for this reason we have ranged freely between all these domains. The latter two, in particular, will form the focus for Chapter 3. This may appear to be rather cavalier; but ‘sustainable’ in each case refers to much the same, although the detail can be quite different. Taking sustainability in a broad sense allows us to compare and contrast facets of application across these domains, and to apply lessons from one arena to another.

In order to provide the reader with some background, we have begun this chapter with a discussion of a few of the current visions of sustainability, with a particular emphasis on sustainable development. There is, of course, an additional and substantial literature on the meaning of development; but this will not be covered here (see Potter et al, 2003, for a summary). The aim will be

to use these visions of sustainability to illustrate some of the difficulties inherent within its concept, and how some people have tried to address these.

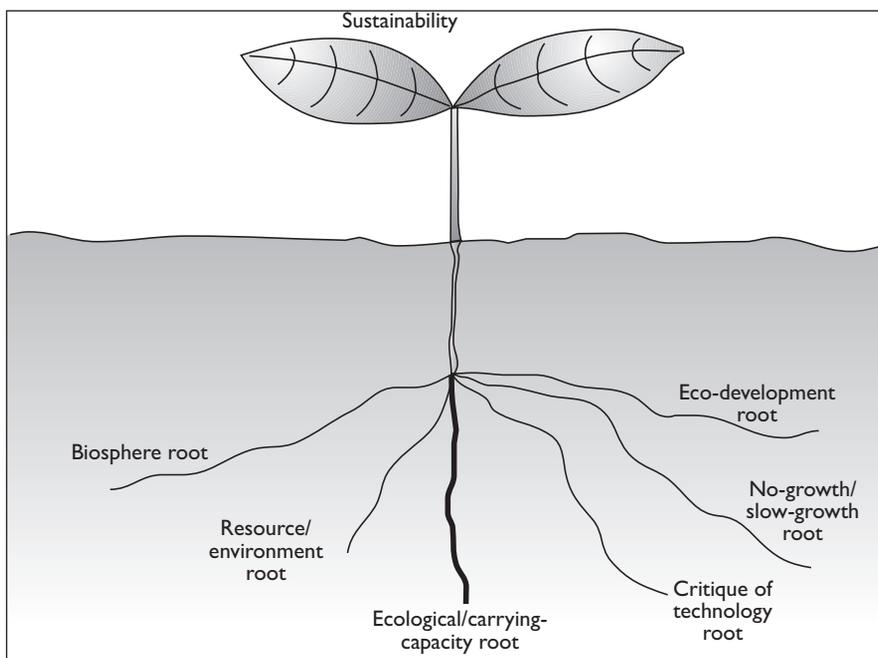
As described above, many individuals have noted the need for measuring sustainability, and this chapter will discuss a few approaches in this direction and the problems that people have faced. Again we cannot claim to be exhaustive; but the examples we have chosen illustrate the broad range of approaches with their associated advantages and disadvantages. In particular, the background to the use of indicators as a means of gauging sustainability will be discussed. Chapter 2 will deal with some specific examples of sustainability indicators in more depth. An important point to make is that the use of simple indicators as a means of following change in complex systems is not new. Biological indicators have been widely employed in environmental science for many years, and in this chapter we compare their use in this context to one of gauging sustainability. The final section of the chapter will draw together some of the main difficulties in using relatively simple indicators to gauge what is, in fact, very complex. These problems will be pursued further in Chapters 2 and 3.

## **Two roots of sustainability**

In its original form, sustainability was closely associated with maintenance of environmental quality, although – as would be expected with a term that is so multifaceted – the origins of sustainability are complex. Excellent discussions can be found in Kidd (1992), Moffatt (1992), Munn (1992), Heinen (1994), Mitcham (1995), McEntire (2005) and Du Pisani (2006) and will not be repeated in depth here. Needless to say, concerns for the environment and views over humankind's place within the environment are ancient. Kidd (1992) suggests that the contemporary view of sustainability in a broad sense has originated from six separate strains of thought (see Figure 1.1). We do not intend to describe each of these; but two of them are particularly relevant for the purposes of this book as they will reappear in various guises in later chapters.

### **Ecological/carrying-capacity root**

Of the six roots in Figure 1.1, a major contribution has come from the first: the ecological concept of carrying capacity and the idea of maximum sustainable yield (MSY) that partly flows from it. Carrying capacity is the notion that an ecological system (ecosystem) can only sustain a certain density (the carrying capacity) of individuals because each individual utilizes resources in that system. Too many individuals (overshooting the carrying capacity) results in overuse of resources and eventual collapse of the population. MSY is a related concept in that it implies a sustainable utilization of a resource. If the MSY is exceeded, perhaps because of population increase or



Source: adapted from Kidd (1992)

**Figure 1.1** *The roots of the modern view of sustainability*

simply because of greed, then the system may collapse with potentially dire consequences for those dependent upon the resource (Botsford et al, 1997; Link et al, 2002).

Carrying capacity has been and remains a central concept in ecology (Meadows et al, 2004) and can be found at the heart of the other five strains of thought in Figure 1.1. For example, the second root ('resource/environment') stems from a number of influential books written during the late 1940s and 1950s that question the ability of the Earth to sustain a growing human population. In other words, these works argue that the Earth is approaching its carrying capacity, and great dangers are ahead if we push too close to, or exceed, that limit. In the introduction to one of these books, written by William Vogt and published in 1949 entitled *Road to Survival*, the author suggests that:

*Road to Survival is, I believe, the first attempt – or one of the first – through fully chosen examples, in large part drawn from wide first-hand experience, to show man as part of his total environment, what he is doing to that environment on a world scale, and what that environment is doing to him. (Vogt, 1949)*

## The critique of technology root

The critique of technology root of sustainability originated during the 1960s and 1970s as a counter to the perceived indiscriminate use and exportation of technologies that may pose dangers to the environment. A classic example is the well-known book by Schumacher entitled *Small Is Beautiful: Economics as if People Mattered* (1973). There are a number of examples that come under the critique of technology, including nuclear power; but probably some of the best-known examples are in agriculture. Indeed, it can be argued that the problems arising from the indiscriminate use of pesticides, in particular, have had a major effect on the evolution of the sustainability concept. These dangers were highlighted in an immensely influential book, *Silent Spring*, written by Rachel Carson and published in 1962. The title invokes a spring without songbirds as they become decimated by the widespread use of pesticides. More recently, we have seen a continued concern over the application of genetic engineering within crops and animals and the coining of the term 'Frankenstein food' by critics. Indeed, it could be argued that agriculture has been at the heart of much of the sustainability debate, and this is not particularly surprising for two main reasons:

- 1 Agricultural systems occupy large areas of land – far more land than any other industry with the possible exception of forestry. Therefore, what occurs within agriculture can often have major environmental effects.
- 2 The end product of agriculture is often food, and we all eat! Agriculture is therefore one of the foundations of human society.

The result has been a move towards the promotion of sustainable agriculture, although terms such as agro-ecology, alternative agriculture, ecological food production, low-input sustainable agriculture (LISA) and organic agriculture have also entered the fray and offer distinctive elements to their proponents. Alternative agriculture is taken to be a sort of antithesis to conventional agriculture without really being very clear as to what either term means (Frans, 1993). LISA is assumed to be sustainable agriculture with an accepted low level of artificial inputs, although where one draws the line between this and high-input agriculture is again rather nebulous. Of all the terms, organic agriculture is the most definable: produce can be certified as organic depending upon the absence of defined substances (mostly pesticides and artificial fertilizers) during production. Indeed, for many the terms sustainable agriculture and organic agriculture have become synonymous precisely because the latter, by definition, minimizes if not eliminates the use of technologies that may pose dangers to the environment. However, do we minimize or eliminate such technologies, and if to minimize is adequate, then by how much?

The answers, quite frankly, are very diverse and depend to a large extent upon who is defining sustainability in each individual context; the specific example of agriculture beautifully encapsulates this central paradox of

### Box 1.1 Visions of sustainable agriculture

- Those who appear to see no problem in equating sustainability with 'high-input', 'high-yield' conventional farming:

*... profitability, consumer safety, resource protection and viability of rural America. (Kelling and Klemme, 1989)*

*What is sustainable agriculture after all? The only sustainable agriculture is profitable agriculture. Short and sweet. (Ainsworth, 1989)*

*... the concept of sustainable agriculture does not exclude the use of fossil fuels and chemicals: it only requires that the criteria of appropriateness and sustainability be applied to the whole system. (Wilken, 1991, quoted in Frans, 1993)*

*One of the key charges of the environmental activists is the claim that high-yield farming is 'unsustainable'. This has resonated with the public, probably because it implies a lurking, hidden threat. Actually ... high-yield farming is more sustainable than organic farming... We also have strong evidence that high-yield farming can continue producing higher and higher yields on into the future. (Avery, 1995)*

- Those who do not appear to equate sustainability with high-input, high-yield conventional farming:

*'Sustainable' means the capability to continue producing food and fibre indefinitely and profitably without damaging the natural resources and environmental quality on which all of us depend. (Schaller, 1989)*

*For a farm to be sustainable, it must produce adequate amounts of high-quality food, protect its resources and be both environmentally safe and profitable. Instead of depending on purchased materials such as fertilizers, a sustainable farm relies as much as possible on beneficial natural processes and renewable resources drawn from the farm itself. (Reganold et al, 1990)*

*A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability and social justice among all sectors of society. (Allen et al, 1991)*

*... sustainable agri-food systems are systems that are economically viable, and meet society's need for safe and nutritious food, while conserving or enhancing ... natural resources and the quality of the environment. (Science Council of Canada, 1991, cited in Lehman et al, 1993)*

*Sustainable agriculture refers to the use of agricultural land in such a way to ensure that over time no net quantitative or qualitative loss of natural resources occurs. (Fresco and Kroonenberg, 1992)*

*Sustainable agriculture consists of agricultural processes – that is, processes involving biological activities of growth or reproduction intended to produce crops which do not undermine our future capacity to successfully practice agriculture. (Lehman et al, 1993)*

*Only the most hard-bitten of intensive commercial farmers would now accept that conventional agriculture is sustainable. (Gibbon et al, 1995)*

sustainability. The comments in Box 1.1 provide a simple illustration of these diverse viewpoints. As can be seen from these, there are marked contrasts in how people envisage sustainable agriculture, and the views of Avery (1995) and Gibbon et al (1995) are very hard to reconcile.

## The meaning of sustainability

The confusion over the meaning of sustainable agriculture is also apparent when the meaning of sustainability in other arenas – for example, in sustainable development – is considered. Although most would agree that sustainability implies ‘not cheating on your kids’, a clearer definition has proved to be elusive. This is a point that has been noted by many and appears to be a source of much frustration. Almost every article, paper or book on sustainability bemoans the fact that the concept is broad and lacks a broad consensus; this is usually followed by the authors’ own preferred definitions, which in turn add to the lack of consensus! Some examples of this diversity can be found in Box 1.2, although it should be stressed that the examples in Box 1.2 are by no means indicative of the entire range of definitions that exist or, indeed, of the main elements that tend to be mentioned. To do this would be labouring the point and would make for rather staid and boring reading.

Given its ubiquitous use and popularity, the lack of a concrete definition of ‘sustainable’ may appear to be very surprising. How can something so

### Box 1.2 Some definitions of sustainability

- General definitions of sustainability include the following:

*... the capacity of a system to maintain output at a level approximately equal to or greater than its historical average, with the approximation determined by the historical level of variability. (Lynam and Herdt, 1989)*

*... maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time. (Pearce and Turner, 1990)*

*The sustainability of natural ecosystems can be defined as the dynamic equilibrium between natural inputs and outputs, modified by external events such as climatic change and natural disasters. (Fresco and Kroonenberg, 1992)*

- Definitions of sustainable development:

*... development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations. (WCED, 1987)*

*... development that improves the quality of human life while living within the carrying capacity of supporting ecosystems. (IUCN, 1991)*

vague be so popular? The essence of the problem has been captured by Schaller (1993): ‘As a destination, sustainability is like truth and justice – concepts not readily captured in concise definitions.’ We all want truth and justice; but what these mean can also vary greatly from individual to individual and between societies. My justice may be your exploitation, and my truth may be your lies! Indeed, this failure to obtain a universal and concise definition of sustainability has led some authors to take what may be thought of as a rather extreme position:

*Many would argue that it is important to define what sustainability is, or might be, before any actions can be taken towards setting up more sustainable agricultural practices. We do not necessarily subscribe to the need to define sustainability in order to practise it; but the exercise of definitions is one useful way to examine several perspectives and to understand competing views. (Gibbon et al, 1995)*

This would seem to be an illogical stance and somewhat perversely hinges on what is meant by the term ‘define’. If by ‘define’ we mean summarize in a single sentence what is meant by sustainability, then one can have some sympathy with the Gibbon et al (1995) statement that alludes to an unnecessary and unhelpful strait-jacketing of such a complex notion. But if the meaning of ‘define’ is extended more broadly, then the statement must surely be wrong. After all, how can we do something unless we know what we are trying to do? Surely we cannot farm or develop sustainably unless we know what this implies? If we don’t know what we are trying to get, how do we know if we have it? While one can sympathize with the view that a simple, concise definition may not be possible, surely some idea of where one is trying to go is an absolute necessity. Even a statement of intent that some factors should increase while others decrease, without specifying an ultimate goal, is still a definition. For example, the Natural Step framework sets out guiding principles (or system conditions) for achieving sustainability (James and Lahti, 2004), which broadly demand that:

- Materials from the Earth’s crust must not be systematically increased in the Earth’s environment.
- Materials produced by society must not be systematically increased in the Earth’s environment.
- The physical basis for the productivity and diversity of nature must not be systematically diminished.
- There must be fair and efficient use of resources with respect to meeting human needs.

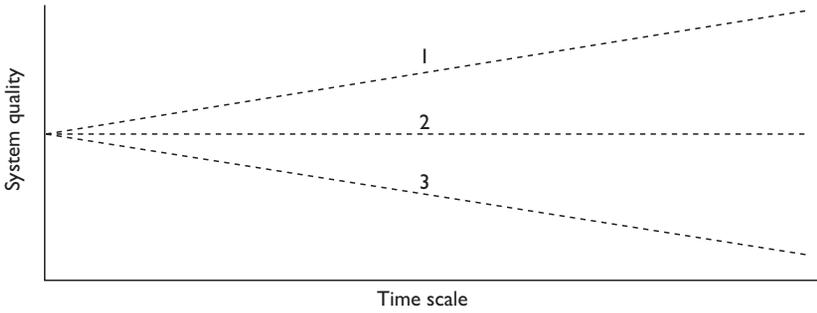
While not set out here as a formal ‘two-sentence’ definition, such as that of the WCED (1987), the principles do define what should and shouldn’t be done in order for sustainability to become a reality.

This uncertainty over the meaning of sustainability has not reduced the popularity of the concept. On the contrary, it could, perhaps, be cynically argued that the resulting flexibility has allowed the concept to attain the heights that it has. If those involved in sustainable development can give their own individual ‘spin’ to the meaning of sustainability, then all definitions can remain fashionable and mainstream, and this may help to strengthen its popularity. The uncertainty may, in fact, be self-reinforcing and sustainable in its own right. In a less cynical vein, this flexibility as to what sustainability means can also be a great strength in a very diverse world. People differ in the environmental, social and economic conditions within which they have to live, and having a single definition that one attempts to apply across this diversity could be both impractical and dangerous. As Kidd (1992) argues: ‘there is not, and should not be, any single definition of sustainability that is more logical and productive than other definitions’.

Why is there so much diversity in viewpoint regarding the meaning of sustainability? After all, the oft-quoted World Commission on Environment and Development (WCED, 1987) definition of sustainable development appears to be a reasonable stance. Some of the fundamental reasons for this are briefly illustrated in Figure 1.2a. In this figure sustainability is represented by a change in a property referred to as ‘system quality’ – a very subjective term open to all sorts of value judgements. Sustainable equates to a situation where quality remains the same or increases. If quality declines, then the system can be regarded as unsustainable. This may at first sight appear to be clear; but there are numerous problems that arise even in this simple figure. These can be listed as follows:

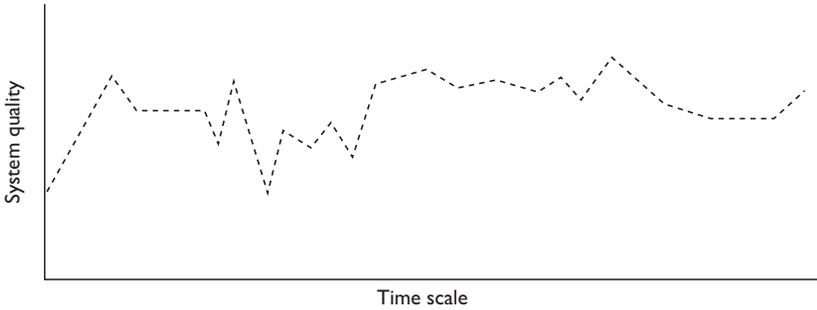
- What exactly is the system to which we are ascribing some notion of quality? Who is in this system and who isn’t? This may equate in a rather crude sense to the spatial dimension of the system being evaluated, and one can ask where the system ‘boundary’ resides? Indeed, is there really a boundary at all?
- What do we take as a time scale across which quality is being gauged? For example, in Figure 1.2b, system quality fluctuates with time; but taken across the whole length of the time axis, it remains more or less the same (= sustainable). If one only looked at small segments of the time axis rather than the whole length, the picture could be quite different. Some segments show marked unsustainability as quality declines rapidly, while other segments show a rapid increase.
- What is meant by system quality and how is it determined? This problem is probably the most intractable. Quite frankly, given the same system and time scale, it is possible for two people to arrive at very different views depending upon what they see as important components of quality (see Figure 1.2c). To one person the quality may be increasing, while to someone else it is decreasing. This point can be illustrated from another angle – the costs of achieving sustainability, or what some call the

(a) Simple (one indicator)

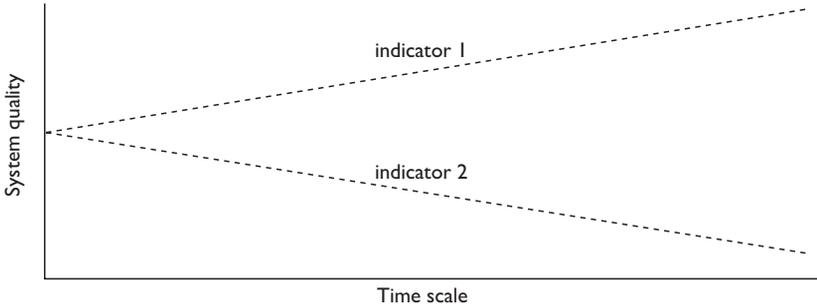


- 1 = sustainable (increase in quality)
- 2 = sustainable (quality remains constant)
- 3 = unsustainable (quality declines)

(b) Complex (one indicator)



(c) Simple (two indicators)



**Figure 1.2** *System quality and sustainability*

‘profitability versus environment debate’ (Schley and Laur, 1996). In the literature there is frequent reference to two types of sustainability (see Box 1.3) depending upon the costs incurred in attaining them: strong sustainability and weak sustainability (Neumayer, 2003).

There are fundamental differences between strong and weak sustainability, and they can be regarded as mutually exclusive rather than as two ends of a spectrum. Quite simply, if one believes that sustainability should be strong,

### Box 1.3 Two different visions of sustainability

- 1 *Strong sustainability*: in strong sustainability there is little, if any, consideration of the financial or other costs of attaining sustainability. It equates to what some call ecological sustainability and the focus is primarily on the environment. In this case, system quality is taken in terms of the physical measures of things (e.g. population, soil erosion and biodiversity).
- 2 *Weak sustainability*: the second type of sustainability is referred to as weak sustainability. Costs of attainment (financial or otherwise) are important and are typically based on a cost–benefit analysis (CBA), which inevitably involves trade-offs between environment and social and economic benefits. Weak sustainability equates to a sort of economic sustainability where the emphasis is upon allocation of resources and levels of consumption, and financial value is a key element of system quality.

then no trade-off between economic gain and environmental quality is acceptable. It should be noted that this is not just a matter of sentimentality. The strong sustainability argument implies that the environment is critical for our and our children’s survival, and any damage will have negative repercussions. If one believes in weak sustainability, then environmental quality can be traded against economic gain; indeed, to help make all of this easier, the environment is ‘valued’ in monetary terms. Of these two the weak sustainability form is the one that currently dominates in the global economy.

The three questions regarding spatial and time scales and meaning of ‘quality’ have to be resolved before sustainability can be achieved because they provide the context within which the process takes place. In any one circumstance the answer may not appeal to all; but individuals need to have a clear vision as to what is being attempted. In the following sections we examine these questions in greater depth and illustrate how some people have attempted to provide answers. We begin with a discussion of spatial and time dimensions, and we progress to that most intractable of questions: what comprises system quality?

## Space and time in sustainability

As mentioned above, there are two questions that need to be answered before achieving sustainability:

- 1 Over what space is sustainability to be achieved?
- 2 Over what time is sustainability to be achieved?

The answers to these may, at first, appear rather obvious. The spatial scale may correspond with a farm, village, town or city, region, country and so on until the whole planet is considered. However, the difficulty is that these scales

are all interlinked. The smaller the scale, the harder it is to know where to draw the line. In other words, where does the system boundary reside? If the aim is to change the agriculture in an area from what is considered to be unsustainable to sustainable, then are the units for consideration fields, farms or a collection of farms? If the latter, where does the 'collection' stop? Political boundaries (such as local government, state or county) may not be of much theoretical use. Even within clear spatial units such as villages, towns or cities, there are difficulties. Urban areas are not self-contained entities, but have links with other urban areas and the rural environment, which may extend for many miles around the centre. Sustainability in the urban area may be heavily influenced or even dependent upon what happens outside of that area. Do we include these? Sustainability in urban centres will be returned to in more depth in Chapter 3. Even if a boundary can be defined, what lies outside it can be of great importance.

From a theoretical perspective, the spatial scale is clearly very important when one attempts to put sustainability into practice or when one judges the level of sustainability of an existing system. However, even if individuals can clearly define the boundary, there are problems in implementing sustainability. To begin with, there are simple logistical considerations brought about by limited budgets. The larger the scale and the more unsustainable the system, the bigger this problem is likely to be. What does one do? Redraw the spatial scale to take account of the budget? Limit one's objectives and perhaps even abandon the goal of full sustainability? Even worse may be the fact that development funding and, hence, project boundaries may well have to work within political borders, rather than with more reasonably formulated system boundaries. Clearly, what comprises the spatial scale for sustainability is of major importance and is by no means simple.

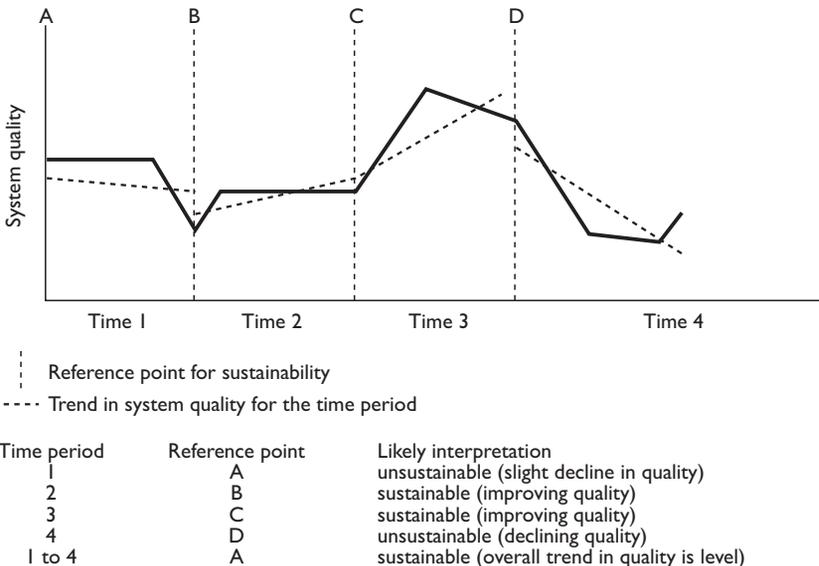
There are numerous examples in the literature illustrating how the spatial scale has been defined. In some cases, the boundary of the system was a defined 'settlement' (Izac and Swift, 1994; Jansen et al, 1995). Indeed, the clearest examples of defined spatial scales are those based on human habitations. 'Sustainable cities' is now a common phrase, and there are even awards for the most sustainable city in a number of countries and regions. One of the pioneers is the Sustainable Seattle programme in the US.

The time scale over which sustainability occurs is a further dimension. The definitions in Box 1.2 imply an intergenerational scale (also referred to as 'futurity') to sustainability, but over how many generations? Does one consider 10, 100 or 1000 years? Different systems may well require different time scales. Another complication is that different components of sustainability in the same system may best be measured in different time frames. For example, agricultural sustainability has a number of elements, including build-up of pests and levels of land degradation. In this case, Harrington (1992a, 1992b) suggests that pest problems are best looked at over scales of 5 to 20 years, while land degradation requires scales of 20 to 100 years. Indeed, Harrington (1992a, 1992b) also suggests that some factors are best looked at over 1000 years,

although achieving this would certainly be a challenge unless one limits oneself to historical trends.

A very practical consideration flows from this discussion of relevant time scales. In Boxes 1.1 and 1.2, the reader encounters words such as current, future, improve, maintain, equilibrium, conserve and enhance. All of these words have one thing in common: they are relative and thus are open to the influence of personal values. This relativity lies at the heart of sustainability, and the latter is only meaningful if it is based on a trend over time and if we apply a value judgement as to what that trend should equate to. The non-attainment of ‘sustainable’ becomes *de facto* ‘unsustainable’. Clearly, a starting point, or reference condition, is required in order for the trend to be gauged; but the choice of the starting point can influence the results.

Figure 1.3 presents an admittedly simplistic explanation of the problem. As in Figure 1.2, this figure presents the change in system quality over time; but the time axis has been divided into four blocks (each representing ten years, perhaps). The vertical lines labelled A, B, C and D are arbitrary starting points for the gauging of system quality. Over all four time periods, quality fluctuates; but a general trend would be more or less horizontal as, indeed, it was in Figure 1b (no increase or decline). However, if divided into smaller time horizons that may, perhaps, equate more to human planning horizons (e.g. ten years), then the interpretation of the trend in each block of time may be quite different. The last segment (number four) suggests a very unsustainable system, while segment three suggests the opposite. To make things even more complex, it is apparent that the situation could be quite different with smaller (e.g. five years) or larger (e.g. 20 years) scales. Although fixing a scale at X years (no matter how arbitrary) provides some clarification, it does not in itself yield all the



**Figure 1.3** *Importance of the reference point for gauging sustainability*

answers. Clearly, we need to know where the length of the time scale is to start. Even if the time scale is kept constant at X years, one could ‘prove’ almost anything one wishes by careful selection of the starting point in Figure 1.3.

## System quality

Spatial and time scales are key components of achieving sustainability; as has already been stressed, they are problematic in the sense that careful selection of scale or reference point can be used to prove almost anything. However, as difficult as these may be, they pale when put alongside another consideration in sustainability: the meaning of system quality and, in particular, the meaning of quality of life as an element of system quality. This element is a key component of many definitions of sustainability (especially sustainable development) and reflects a major evolution in the ‘sustainable’ concept. Earlier views of system quality and sustainability focused on the natural resource base and environment, with emphasis on physical entities such as the level of water and air pollution, soil erosion, soil acidity or alkalinity, crop yield, biodiversity, and so on. Gauging these over particular spatial and time scales may be difficult, and interpreting the results is open to some debate; however, at least one is dealing with measurable factors, and system quality may be expressed in a manner that is a composite of these. Later considerations of sustainability began to question whether human quality of life should be included as a component within system quality and, hence, sustainability, particularly since we are usually concerned with the sustainability of systems within which humans not only have a stake, but which they actively manage (Jeffrey, 1996; Phillipps, 2006). Sustainability, like development, is all about people, and there may be little point achieving a sustainable system that reduces the quality of life of the people in that system. This issue is returned to in Chapter 6.

Although a logical extension of the sustainability concept, this complicates the issue further. Just what does quality of life comprise? In a book as short as this it is simply not possible to discuss this question in any sort of depth. Indeed, an entire journal (*Quality of Life Research*) is dedicated to the topic. Perhaps one of the most quoted definitions is that of the World Health Organization (WHO):

*An individual’s perception of their position in life, in the context of the culture and values in which they live and in relation to their goals, expectations, standards and concerns. (WHOQOL Group, 1995)*

This definition is full of subjectivity and once looked at carefully says very little. Yet it is these very terms that many would see as central to what sustainability should be about maintaining or enhancing: people’s standards and concerns. We will return to the key issue of ‘expectation’ later in the book.

There are a number of terms used more or less synonymously with quality of life, such as well-being. However, others see these as being quite distinctive. For example, a related term – level of living – has been defined by Knox (1974) as ‘the level of satisfaction of the needs of the population assessed by the flow of goods and services enjoyed in a unit time’.

Although the approach of including quality of life within sustainability has been broadly accepted, especially when expressed in the somewhat vague language of the World Health Organization Quality of Life (WHOQOL) definition, there is not so much unanimity about what it means in practice and how it should be assessed. Pollution and erosion may be measured; but how can quality of life and well-being be assessed? There are numerous examples of gauging well-being through employment, income, crime, travel, migration and house prices. However, just which of these or others are important will presumably vary dramatically from individual to individual and over time. Calibration and interpretation would also appear to be problematic. Are they all to be treated equally, or is crime to be rated higher than travel? What about leisure activities and culture? Although the inclusion of quality of life considerations within sustainability may be desirable, the practice appears to raise many difficult questions.

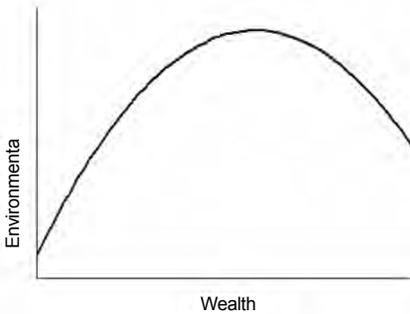
An illustration of the problems inherent in the meaning of ‘system quality’ can be seen in what must surely rank as one of the most iconic images in sustainability: the Environmental Kuznets Curve (EKC). The EKC embodies a sense of the tensions we experience today with the growing impact of emerging economies, such as those of China and India, upon the Earth’s environment. It is named after a Noble Prize-winning economist – Simon Kuznets – who suggested that income equality had a curved relationship to national income (see Box 1.4). As the economy grows, there is an initial increase in income inequality; but at a certain point of inflection the curve turns downwards and income inequality lessens (the population becomes more equal). It was not until the early 1990s, ironically after Kuznets’s death, that others began to think that his famous curve could equally apply to the relationship between environmental degradation and income. They reasoned that degradation would initially increase as a country industrialized and wealth increased, but would reach a point of inflection where matters would improve. This could, perhaps, be because of greater control over pollution through legal or voluntary measures, or perhaps because of better technology or a switch away from heavy industry to services. As a result, we have the classic ‘good news’ story for sustainability – yes, things do get worse, but only for a while. Once wealth exceeds a critical point, then the environment improves, or at least the degradation lessens, which is not quite the same thing.

Many have tried to prove that the EKC exists (Harbaugh et al, 2002; Khanna and Plassmann, 2004) and Box 1.4 is but one example. It has not been as easy as the reader may suppose, and, indeed, this one graph illustrates almost all of the contentious issues at the heart of sustainability. To begin with, it reduces human existence to just two dimensions: environment and income.

### Box I.4 The Environmental Kuznets Curve (EKC)

#### The theory

The relationship is quadratic in form:



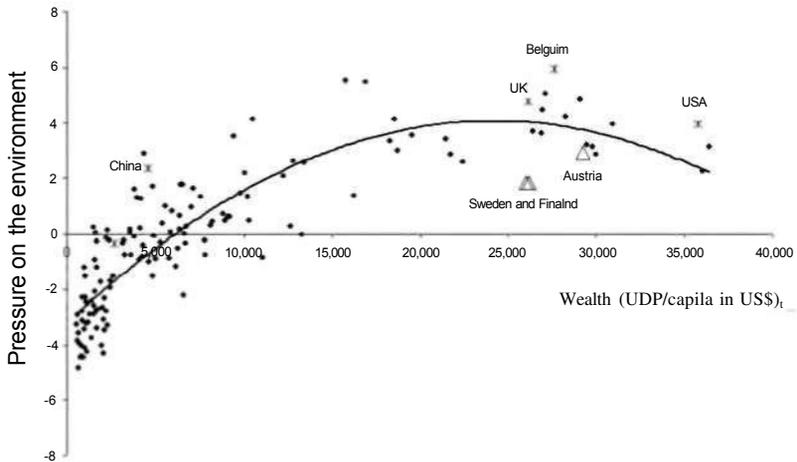
$$y = a + b x - c x^2$$

Degradation increases with wealth until at a certain point degradation lessens. This could be due to closure of polluting companies (or relocation) and the introduction of new methods of production and technologies to lessen pollution.

#### The evidence

This figure has been adapted from Morse (2008). The vertical axis represents pressure on the environment, while the horizontal axis is national wealth, assessed here by gross domestic product (adjusted for purchasing power parity) per capita.

The regression line shown in the graph is statistically significant and suggests that as wealth increases, largely because of industrialization, pressure on the environment from



pollution, etc. increases. At an income of around US\$24,000 per capita, the pressure on the environment lessens. The reasons for this may be varied, including the introduction of new technology to lessen pollution or even the closure of some of the polluting companies.

Each point in the graph is a country. Some countries (such as the UK, the US and especially Belgium) have pressures on the environment that are greater than would be predicted by the regression for their wealth. However, note how some other countries (Sweden, Finland and Austria) have similar levels of wealth as the UK and Belgium, but much less pressure on the environment.

The simplistic implication of the EKC for a country such as China that has a relatively low level of wealth, but much pressure on the environment, is to increase its wealth as rapidly as possible in order to reach and exceed the point of inflection.

The EKC is based on an assumption that once a population reaches a certain quality of life, they will begin to value the environment and place pressure on polluters and degraders to do the same; but why should income be the sole or best measure of well-being? It would also seem that one can be happily ‘traded’ against the other – an initial decline in environmental quality appears to be fine if accompanied by an increase in wealth (= well-being?) provided the point is reached where the curve starts to turn downwards. This is the weak sustainability argument. Also note that each dot in the figure in Box 1.4 is a nation state, but could equally be any spatial unit where environmental degradation and income can be measured. The assumption, of course, is that the spatial units have a feedback mechanism so that at some point of wealth there is pressure to reduce degradation. But what exactly is meant by ‘environmental degradation’, how it should be measured and by whom, and what are the limitations of the national state as a spatial scale? The latter, of course, is problematic because the forces that cause such degradation (pollution and consumerism) can readily pass across our artificial boundaries. Visualizing the environment in different ways or using different methodologies could generate many versions of the EKC, even some without any inflection point at all suggesting that degradation may slow down but there is no reversal. Thus, while the figure in Box 1.4 may look very objective and scientific, it can hide much underlying subjectivity. Does it matter? Well, if we consider that some countries may take the EKC as ‘truth’ and, hence, push along the wealth axis at any cost with the assumption that environmental degradation will eventually reduce, then it can have major repercussions for us all.

## **Sustainability in practice**

While the previous sections have discussed some of the questions central to sustainability, we are faced with a conundrum. Although sustainability may have much in common with truth and justice – what it comprises is heavily influenced by value judgements and ethics – like these two, it has to be put

into practice by imperfect human beings. Given that sustainable development, like agriculture, cities and institutions, is a practical goal to be reached by intervention of some sort, one clearly needs to be aware of whether the system is still unsustainable or whether the goal of sustainability has been reached. Obviously, this will depend upon one's particular vision of sustainability and answers to questions regarding relevant spatial and time scales; however, even so, once the goal has been clearly identified, one needs to know whether the target has been reached:

*Sustainability must be made operational in each specific context (e.g. forestry, agriculture), at scales relevant for its achievement, and appropriate methods must be designed for its long-term measurement.*  
(Heinen, 1994)

An illustration of the approach taken in this direction is provided by the results of a meeting held in November 1996 at Bellagio, Italy. The meeting was funded by the Rockefeller Foundation, and the aim was to set some principles for monitoring progress towards sustainable development. The results of the meeting are referred to as the Bellagio Principles for sustainable development (Hodge and Hardi, 1997) and are summarized in Box 1.5.

Some of these address broad issues already discussed, namely the:

- need for a clear definition (principle 1);
- focus on holism in sustainability (principle 2);
- importance of time and spatial scales (principle 4).

These are elements closely associated with the goal of sustainable development and finding them listed amongst the first principles in Box 1.5 is no surprise. Clearly, they need to be addressed before any progress on sustainability can be made.

As for gauging sustainable development, principle 5 emphasizes the use of a limited number of indicators, and this is followed by principles 6, 7, 8 and 9, which broadly set out how the indicators should be developed and employed. It should be noted that in recommending the use of indicators for this purpose the Bellagio meeting was simply echoing similar calls made by others. For example, in Chapter 40 ('Information for Decision-Making') of the Agenda 21 document flowing out of the Rio conference in 1992, there is a call for the development of indicators for sustainable development (ISDs). Indeed, there is a strong literature stretching back a number of years before 1992 calling for the use of indicators as a means of gauging sustainability (sustainability indicators: SIs), and indicators have been widely employed in a diverse range of circumstances for perhaps thousands of years. For example, farmers have long employed simple indicators of soil fertility, such as soil colour and presence of certain plant species, and other important considerations in agriculture (including the weather). Biologists have also been developing and applying

### **Box 1.5 A summary of the ten Bellagio Principles for gauging progress towards sustainable development**

- 1 What is meant by sustainable development should be clearly defined.
- 2 Sustainability should be viewed in a holistic sense, including economic, social and ecological components.
- 3 Notions of equity should be included in any perspective of sustainable development. This includes access to resources as well as human rights and other 'non-market' activities that contribute to human and social well-being.
- 4 Time horizon should span 'both human and ecosystem time scales', and the spatial scale should include 'not only local but also long-distance impacts on people and ecosystems'.
- 5 Progress towards sustainable development should be based on the measurement of 'a limited number' of indicators based on 'standardized measurement'.
- 6 Methods and data employed for assessment of progress should be open and accessible to all.
- 7 Progress should be effectively communicated to all.
- 8 Broad participation is required.
- 9 Allowance should be made for repeated measurement in order to determine trends and to incorporate the results of experience.
- 10 Institutional capacity in order to monitor progress towards sustainable development needs to be assured.

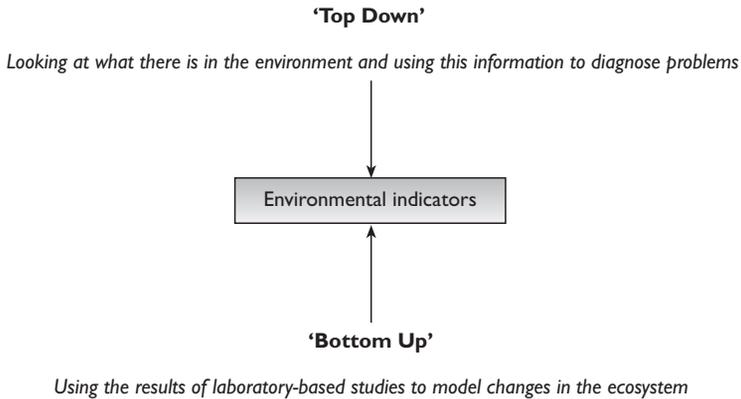
*Source:* adapted from Hodge and Hardi (1997)

indicators to ecological systems for many years. Ecosystems can comprise thousands if not millions of different components, some of which will be living (animals, plants, micro-organisms, etc.), while others will be inert (soil and water). Indeed, people (with all their attendant socio-economic and cultural dimensions) can also be components of the system. Clearly, with thousands, if not millions, of components and interactions in such a system, one cannot measure everything; instead, biologists focus on key components and interactions that represent the system as a whole.

Given the extensive experience of farmers, biologists and others, an extension of the indicator approach into sustainability is certainly not surprising, and one could even say is inevitable. In the following two sections we explore some aspects of the use of indicators to gauge complex systems. We begin by exploring the use of indicators by biologists to monitor the effects of pollution, and then progress to the use of indicators to gauge sustainability.

## **Indicators of ecosystem health**

The widespread introduction of human-made chemicals and other pollutants into the environment has resulted in a substantial literature on the use of biological indicators as a means of gauging environmental impacts or, as some



Two of the most common methods in the top-down approach are to:

- *Measure the biological diversity (biodiversity).* When communities are put under stress (eg pollution), they generally become simpler as some species die and the relatively small number of tolerant species come to dominate the system.

Therefore, more biodiversity = better ecosystem health

- *Use the presence of certain indicator species.* Some species are very sensitive to a change in the environment (temperature, acidity, pollutants etc).

Therefore, presence/number of individuals of these species = better ecosystem health

Source: adapted from Cairns et al (1993)

**Figure 1.4** *The two broad approaches to using environmental indicators*

put it, the health of the ecosystem (see Rapport et al, 1998, for theories and examples). Without wishing to oversimplify what is a complex field, there are two broad approaches to 'environmental indicators' (see Figure 1.4), with the top-down approach particularly popular and comprising two key methods:

- 1 Look for certain 'indicator' species that are sensitive to changes in the environment.
- 2 Measure the biological diversity (biodiversity).

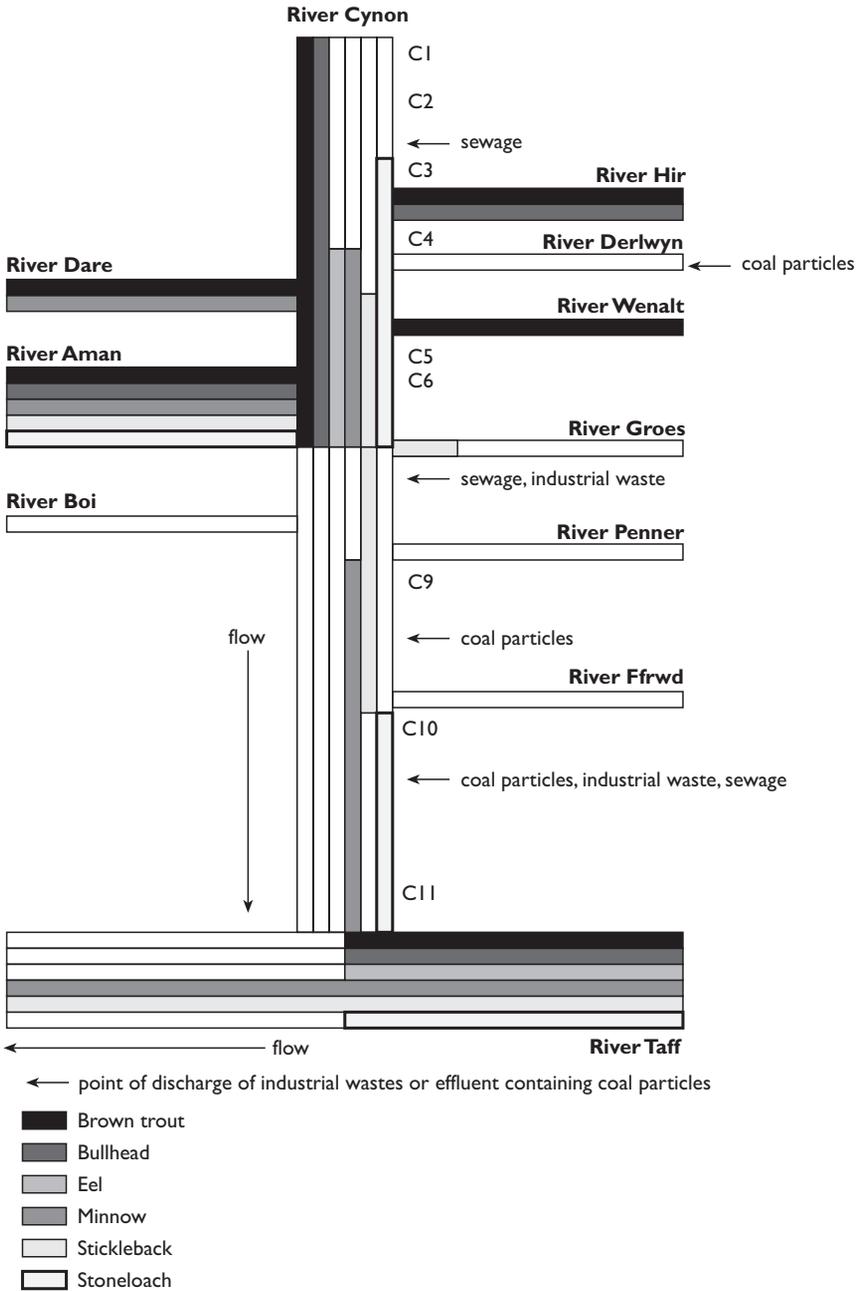
However, in practice, these two will often go together – the indicator species will be the first to be lost when a stressed system shows a reduction in biodiversity.

There are numerous studies that illustrate how species composition reflects ecosystem health, and one could select an example from almost any system or country worldwide. One particular example dating to the late 1960s and early 1970s is provided by Learner et al (1971). This example has the advantage of referring to a system with a clear spatial (and, to some extent, administrative)

and political) boundary – a river and its catchment – covering an area of 108 square kilometres. Furthermore, since a number of the key texts in the sustainability paradigm were published during the early 1970s, an example that predates them may be pertinent.

While published more than 30 years ago, the Learner et al (1971) study follows a commonly used approach in assessing environmental impact. The study is based on a survey of fish and macro-invertebrates (insects, worms, etc.) of the Cynon River, a tributary of the River Taff that flows through Cardiff, the capital of Wales. The study intended to determine how the distribution of species was influenced by effluents from sewers and various industries, including coal washery plants and coal tips that enter the river. Figure 1.5 is a diagrammatic representation of the river and its associated streams, along with an indication of where effluent enters the river and sampling stations (C1, C2, C3, etc.) where the fauna was checked. Distributions of six fish species (such as brown trout, bullhead and eel) are illustrated in Figure 1.5: there were clear effects on fish distribution, especially below the point where the Rivers Groes and Aman join with the Cynon. This corresponds with a major, but intermittent, discharge of industrial effluent. It is also noticeable that of all six species, minnows were found closer to the point of discharge, although this probably reflected their higher mobility and ability to re-colonize rapidly after pollution incidents, rather than an innate ability to withstand the toxicants. The results of the pollution could even be found some distance downstream of the point where the Cynon meets the Taff. Again, minnows in the Taff appeared to be the least affected.

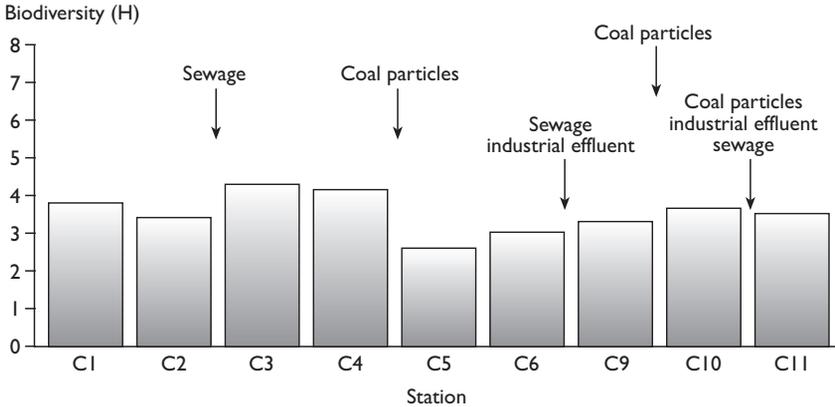
A second method of gauging the state of the environment is to measure biodiversity. Ecologists have been measuring biodiversity for a long time, and various methods and indices exist (Southwood, 1978). These tend to be of a rather technical nature; one example is the Shannon–Wiener Index ( $H$ ) illustrated in Box 1.6. The higher the value of  $H$ , the greater is the biodiversity of the sample. In effect, the index is a composite of the number of species in the sample ( $S$ ) and the number of individuals of each species in the sample (represented by  $p_i$ ). Example calculations of  $H$  are also shown in Box 1.6. The application of the Shannon–Wiener index can be illustrated by using the Learner et al (1971) example already described. Figure 1.6 presents the values of  $H$  for nine of the sampling stations (C1 to C6 and C9 to C11) on the River Cynon (location shown in Figure 1.5). The index has been calculated for species of macro-invertebrates (insects, worms, etc.), and fish and other animals have not been included. As can be seen from Figure 1.6, the value of  $H$  declines between stations 4 and 5, but gradually increases from stations 5 to 11. The point between station 4 and 5 corresponded with a discharge of coal particles into the river, and interestingly did not correspond with the location of the discharge that had a major effect on fish distribution as outlined above (this discharge lies between stations 6 and 9). It is also interesting to note that biodiversity increases between stations 2 and 3, probably as a result of sewerage entering the river and providing a source of enrichment.



Note: C1, C2, C3, etc. are sampling stations.

Source: adapted from Learner et al (1971)

**Figure 1.5** Fish distribution in the Cynon River system in South Wales, UK



Note: arrows indicate points of discharge of sewage, coal particles and industrial effluent.  
 Source: adapted from Learner et al (1971)

**Figure 1.6** *Change in biodiversity (Shannon–Wiener Index, H) along the River Cynon in South Wales*

The advantage of such an index is that it simplifies complexity into a single value that readily allows comparison. However, although this biodiversity index is useful for biologists, it does have a number of limitations.

- Strictly speaking, it can only be applied when the total number of species in the ecosystem is known, although in practice this may not be the case. For example, although Learner et al (1971) included a total of 126 macro-invertebrate species in their survey, and sampling was very thorough, there is no guarantee that all of the species were sampled.
- The index has no qualitative element since the same value of H can be found in the same system that has undergone a dramatic shift in species composition. For example, stations C1 and C10 in the Learner et al (1971) example both had an H value of around 3.7, yet the species composition at those two stations was quite different. In other words, it simply measures biodiversity without allowing for differences in the species that comprise that diversity.
- As can be seen from the equation and calculations, it is a rather technical expression that may not resonate very well with those who are not conversant with biology.

The first limitation is essentially technical in nature. The second represents an inevitable loss of information as we create a simple index out of complex data. The third is not a consideration for biologists fully conversant with the mechanics of H, but would be important if the index was employed as a means of informing policy-makers or the public about environmental quality. Although the fundamental ideas of indicator species and biodiversity do

**Box 1.6 The Shannon–Wiener Index (H) of biodiversity**

$$H = - \sum_{i=1}^{i=S} (p_i) (\log_2 p_i)$$

where:

- $\sum$  = sum of (in this case from species number 1 to species number S);
- S = the number of species;
- $p_i$  = the proportion of total sample belonging to the  $i$ th species. It is found by  $n_i/N$ , where  $n_i$  is the number of individuals in species  $i$  and  $N$  is the total sample size;
- $\log_2$  = logarithm to the base 2.

The negative sign converts the results of the calculation from negative to positive. It is required because the logarithm to the base 2 of values less than 1 is always negative ( $\log_2$  of 1 = 0). The higher the value of H, then the greater is the biodiversity of the sample.

*Examples:* in both cases there are two species ( $S = 2$ ), and the sample size is 100 ( $N = 100$ ).

(a) 50 individuals of each species:

$$\begin{aligned} H &= - (0.5 \times \log_2 (0.5) + 0.5 \times \log_2 (0.5)) \\ &= - (0.5 \times -1) + (0.5 \times -1) \\ &= - (-0.5 + -0.5) \\ &= 1. \end{aligned}$$

(b) 99 individuals of species 1 and 1 individual of species 2:

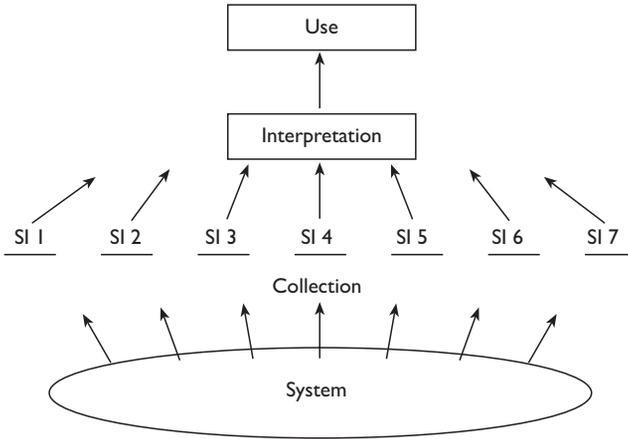
$$\begin{aligned} H &= - (0.99 \times \log_2 (0.99) + 0.01 \times \log_2 (0.01)) \\ &= - (0.99 \times -0.0145) + (0.01 \times -6.6439) \\ &= - (-0.0144 + -0.0664) \\ &= 0.08. \end{aligned}$$

Therefore, H is higher in (a) than (b), suggesting that there is more biodiversity.

resonate with lay people (Hawkins et al, 1994), the means of presentation is critical. Very technical expressions such as H that speak volumes to biologists may simply not be the best format to use in situations where a much wider audience is being addressed.

## Sustainability indicators and indices

Given that indicators have been widely employed by biologists for many years to gauge ecosystem health, it is not surprising that indicators (and indices, which are amalgams of indicators) have been seen by many as the core element in operationalizing sustainability. However, unlike the sort of system



Note: SIs 1 to 7 collect 'pieces' of information (indicated by the arrows) about the large, complex system.

**Figure 1.7** *The concept behind sustainability indicators (SIs)*

described in the Learner et al (1971) example, sustainability incorporates many more dimensions, including quality of life. While the presence of just a few indicator species and the calculation of biodiversity were all useful in tackling the specific problem of pollution in the River Cynon, the frontiers of sustainability are much grander and a number of indicators are almost certainly required. The theory is indicated in Figure 1.7. The values of the seven SIs shown here are gauged; one then has to interpret the results and make use of the interpretation. The problem, of course, is how many and which indicators to use? Clearly, one cannot use every SI that may potentially be available, and an element of simplification, while at the same time maximizing unique and relevant information, is essential.

SIs are often grouped in various ways depending upon what dimension or element of sustainability they are trying to gauge. The simplest division is into two groups:

- 1 *State SIs*. These are SIs that describe the state of a variable. For example, in the case of environmental quality, one may determine the soil's physical and chemical properties, or the concentration of a pollutant in water. Other more social examples may be the human population density, income equality, female and male wage ratio, life expectancy at birth and maternal mortality rate.
- 2 *Pressure SIs* (also referred to as control, process or driving force SIs). These are SIs that gauge a process that, in turn, will influence a state SI. For example, a control SI may be the rate at which a pollutant is passed into the environment. A good example is the amount of pesticide used in an area (e.g. the Biocide Index of Jansen et al, 1995).

State and pressure SIs can be related. An obvious example is that the rate of pesticide application in an area will have a major influence on the measured concentration of pesticides in drinking water. A suite of SIs may need to have both state and pressure SIs included since changes in a state SI may not necessarily provide information on the causes of change. The link between concentration of pesticides in water and application in a river catchment may be clear enough; but life expectancy at birth and income equality will be influenced by many factors, not just one.

This basic distinction between state and pressure SIs was also initially employed by the United Nations for their ISDs (= SIs), flowing out of the 1992 Rio Earth Summit; however, the UN included a third type called 'response' indicators. These are employed to gauge required progress in the response of governments, for example, to achieve adequate values of state and pressure indicators. It is also interesting to note that the term driving force instead of control was preferred by the UN when first developing its list of SIs in order to fully incorporate the notion that impact of a factor on sustainable development can be positive or negative. They regarded 'pressure' as implying a negative dynamic – making matters worse – while driving force can imply both a negative and a positive dynamic – making matters better. In effect, the driving force – state – response (DSR) is a cause–effect model: driving forces generate the state of what is experienced which, in turn, may require something to be done.

A further feature of the UN indicators is that they based their selection of SIs on the chapters of the conference document, so that the latter essentially becomes the frame. The chapters themselves can be broadly divided into four categories:

- 1 social aspects of sustainable development;
- 2 economic aspects of sustainable development;
- 3 environmental aspects of sustainable development – further subdivided into water, land, atmosphere and waste;
- 4 institutional aspects of sustainable development.

A 'working list' of SIs was then determined for points arising in each of the chapters. A summary of the results is presented in Table 1.1. For example, in Chapter 17 of Agenda 21, entitled 'Protection of the Oceans, all Kinds of Seas and Coastal Areas', there were three driving force SIs and two state SIs. The driving force SIs covered population growth in coastal areas and levels of pollution. One of the state SIs followed the first rule given by Rennings and Wiggering (1997) – namely, that resource use should not exceed regeneration. This is the much studied and discussed concept of maximum sustainable yield (MSY) mentioned earlier in this chapter and which will be returned to in Chapter 2. The second state SI for this chapter, the algae index, is an index of algal (includes phytoplankton) biodiversity and abundance. It comprises information on the type and quantity of algae present in a volume of water.

**Table 1.1** *The United Nations working list of indicators of sustainable development (ISDs) based on Agenda 21 (Rio de Janeiro, June 1992)*

<i>Categories, main chapter headings and chapter numbers (bracketed)</i>			
Social	Combating Poverty (3) Demographic Dynamics and Sustainability (5) Promoting Education, Public Awareness and Training (36) Protecting and Promoting Human Health (6) Promoting Sustainable Human Settlement Development (7)		
<i>Driving force: 11</i>	<i>State: 21</i>	<i>Response: 7</i>	
Economic	Changing Consumption Patterns (4) Financial Resources and Mechanisms (33)		
<i>Driving force: 9</i>	<i>State: 11</i>	<i>Response: 3</i>	
Environmental	Promoting Sustainable Agriculture and Rural Development (14) Combating Deforestation (11) Conservation of Biological Diversity (15) Protection of the Atmosphere (9) Environmentally Sound Management of Biotechnology (16)		
<i>Driving force: 22</i>	<i>State: 18</i>	<i>Response: 15</i>	
Institutional	Science for Sustainable Development (35) Information for Decision-making (40) Strengthening the Role of Major Groups (23–32)		
<i>Driving force: 0</i>	<i>State: 3</i>	<i>Response: 12</i>	
Total	Driving force: 42	State: 53	Response: 37

Total number of sustainability indicators = 132

*Example: Protection of the Oceans, all Kinds of Seas and Coastal Areas (Chapter 17)*

<i>Driving force</i>	<i>State</i>	<i>Response</i>
Population growth in coastal areas	Maximum sustained yield for fisheries	None
Discharges of oil into coastal waters	Algae index	
Releases of nitrogen and phosphorus to coastal waters		

*Note: the UN prefers to use the term 'driving force' instead of 'control', 'pressure' or 'process' SIs.*

The story of the UN list of SIs, and how it has evolved since the early 1990s, can be found at [www.un.org/esa/sustdev/natlinfo/indicators/isd.htm](http://www.un.org/esa/sustdev/natlinfo/indicators/isd.htm). The UN published the results of its third revision in 2006 (the other two were published in 1995 and 2001), 14 years after the Rio conference, and is encouraging countries to test the SIs. Interestingly, it has abandoned the DSR framework in favour of a theme (poverty, governance, health, etc.) and sub-theme (income poverty, income inequality, life expectancy at birth, etc.) approach.

It has to be said that while the UN has dropped the DSR framework, it does remain popular. Indeed, some have also added ‘impact’ between state and response to give DSIR (driving force state impact response). Impact indicators could be factors such as the incidence of lung disease in humans, which in turn would be influenced by the level of air pollution. At the most sophisticated level, some have suggested the full framework of DPSIR – driving force, pressure, state, impact and response. The distinction between driving force and pressure in this framework can be illustrated as the link between ‘number of cars’ and car exhaust pollution. The ‘number of cars’ or, more accurately, the ‘car density’ is a socio-economic driver (pardon the pun), itself related to a range of factors, such as income levels or, indeed, ‘fashion’, and this driver will, in turn, affect the air pollution pressure (rate of release of noxious gases from car exhausts). The state of air pollution can be measured, and this could impact upon human health. An example of a response would be a tax on petrol purchases to encourage people to drive less.

Nevertheless, although there is much agreement that SIs are the way forward, there is disagreement over what SIs to use and even about the broad nature and characteristics of the SIs. However, the decision over what SIs to adopt is vital to the final outcome. Included here are just four more examples to provide the reader with a taste of the diversity of approach. No doubt the reader will have their own favourites and may wonder why they are not included here; but our choice has been designed to represent points of spread and associated issues, rather than any notion of them being the ‘best’ of their kind.

## **Sustainability indicators: Example I**

Another indicator framework developed as a response to the Agenda 21 document of the Rio Summit is provided by Harger and Meyer (1996). The framework was created by a UN interagency working group for South and South-East Asia, and, as would be expected, there is much overlap with the original UN SI list. Agriculture, fisheries, population and education all feature, and for the most part the indicators have much in common with the UN list described above. But this example has been chosen because there are some interesting and unique additions that illustrate the breadth of what could and arguably should be considered within sustainability. Military considerations, for example, are listed as a category and one can but speculate over what SIs could be included here and how they are to be measured and presented, given the enormous sensitivity of such a topic at any time, but with especial resonance given the events following the terrorist attacks of 11 September 2001 in the US and subsequent military interventions and terrorist attacks across the globe. The relationship between terror and sustainability is, unfortunately, going to be a growing theme during the early years of the 21st century. After all, returning to the quality-of-life definition provided by

WHOQOL (1995), which is contemporary to the Harger and Meyer (1996) paper, the perceived chances of being a victim of terrorism are clearly of major importance.

The Harger and Meyer (1996) paper sets out the following characteristics for SIs:

- simplicity;
- scope: the SIs should cover the diversity of issues mentioned above (environmental, social and economic) and overlap as little as possible;
- quantification: the SIs should be measurable;
- assessment: the SIs should allow trends with time to be determined;
- sensitivity: the SIs should be sensitive to change;
- timeliness: the SIs should allow timely identification of trends.

Unsurprisingly, these have much in common with the Bellagio Principles (Hodge and Hardi, 1997); indeed, there is much here in common with the selection of suitable bio-indicators by biologists to measure pollution or some other environmental change. The quantum jump from bio-indicators to SIs is clearly in the scope – the need for a range of SIs that cover the breadth of the sustainability vision.

## **Sustainability indicators: Example 2**

Bossel (2001) has developed a system-based approach to developing SIs that is, perhaps, the most deeply rationalized of the four examples provided here. The framework attempts to provide a holistic vision of sustainability which recognizes that any system does not exist in isolation and that boundaries are permeable. No matter how we draw our boundaries, any system provides an influence and, in turn, is influenced by other factors that exist outside those boundaries. Bossel also sets out what he regards as ‘six fundamental environmental properties’ – namely (in his words):

- 1 *A normal environmental state.* The actual environmental state can vary within a certain range and still remain normal.
- 2 *Resource scarcity.* The resources (energy, matter, information, etc.) required for a system’s survival and development are not immediately available when and where needed.
- 3 *Variety.* The system environment is seldom uniform; many qualitatively different processes and patterns of environmental variables occur and appear in the environment both constantly and intermittently.
- 4 *Variability.* The state of the environment fluctuates within the normal environmental range in random ways, and these fluctuations occasionally take the environment outside this range.

- 5 *Change*. Over time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state.
- 6 *Other systems*. The environment contains other systems or agents whose behaviour may have system-specific significance for the given system. (Bossel, 2001)

These are simplifying assumptions, of course; but they are reasonable nonetheless. Bossel (2001) then goes on to suggest seven orientors of ‘system viability’:

- 1 (X) existence;
- 2 (E) effectiveness;
- 3 (F) freedom of action;
- 4 (S) security;
- 5 (A) adaptability;
- 6 (C) coexistence;
- 7 (P) psychological needs;

and these are assessed within three sub-systems:

- 1 human;
- 2 support;
- 3 natural.

An indicator is developed for each ‘orientor’ within each sub-system = 21 indicators. Biodiversity, for example, appears as an indicator for ‘adaptability’ in the ‘natural’ sub-system. The key contribution of such a rationalization of system characteristics, orientors, etc. is to avoid:

*... arbitrariness implicit in current and proposed indicator sets. It turns the focus from an uncertain ad hoc search and bargaining process to a much more systematic procedure with a clear goal: to find indicators that represent all the important aspects of viability, sustainability and performance.*

But specifying a framework like this still leaves plenty of scope for subjectivity in terms of SIs. Bossel (2001) attempts to address this by providing guidelines for the selection of SIs; but even so there is much room for personal choice. For example, he refers to ‘air quality’ as an indicator of ‘co-existence’ in the ‘support’ sub-system; but as we will see, this is a highly subjective term and much depends upon how it is measured, when and by whom.

A second feature of the Bossel (2001) approach that distinguishes it from the other three examples presented here is the identification of the need for people to be engaged in SI development, rather than it being a ‘top-down’ and

expert-driven process. This is a central theme of this book and will be returned to later.

### Sustainability indicators: Example 3

Izac and Swift (1994) have developed a matrix of SIs for small-scale agriculture in sub-Saharan Africa (see Table 1.2). The two scales of the matrix relate to spatial scale (cropping system, farm and village) and three categories of ‘products’ from the system (main products, by-products and amenities). As can be seen from the table, production forms a major element of their vision of sustainability. A second distinguishing feature of their framework is their clear identification of the important spatial scale as the ‘village catchment’. While this is something of a movable line in the sand, it is at least an attempt to set out a defined spatial boundary (rather than a conceptual one) within which to assess sustainability. Izac and Swift (1994) also set out a time scale to assess the trend of their indicators – at least ten years. While both decisions can be open to critique (e.g. what about socio-economic relationships outside the village catchment?), they have at least provided a basis for analysis.

**Table 1.2** *Some sustainability indicators proposed by Izac and Swift (1994) for sub-Saharan African agro-ecosystems*

	<i>Cropping system</i>	<i>Scales Farm</i>	<i>Village</i>
Products	Ratio of annual yield for all products to potential and/or farmer’s target yield	Profit of farm production	Economic efficiency
By-products	Soil pH, acidity and exchangeable aluminium content Soil loss and compaction Ratio of soil microbial biomass to total soil organic matter Abundance of key pest and weed species	Ratio of profit to farmer’s target income	Social welfare
		Ratio of aggrading to degrading land area	
		Nutritional status of household	Nutritional status of community
			Stream turbidity, nutrient concentration and acidity
Amenities		Drinking water quality	Human diseases and disease vectors Biodiversity and complexity
		Source and availability of fuel	Drinking water availability

Source: adapted from Izac and Swift (1994)

A second feature of the Izac and Swift (1994) framework that distinguishes it from the others given here is its focus on research. The framework was derived to help guide agricultural research policy, and thus the intended users are also clearly defined and, in fact, are a specialized group. The other three examples are vaguer with regard to intended users, perhaps because they have a much larger and more diverse group in mind.

## **Sustainability indicators: Example 4**

The fourth example is the most recent and is, perhaps, the most ambitious of those presented here. The example selected is the Environmental Sustainability Index (ESI). The ESI was created towards the end of the 1990s by Yale and Columbia Universities in the US, a group which refers to itself as the Global Leaders of Tomorrow and is promoted by the World Economic Forum (WEF). Unlike the other three examples, the ESI is a single number derived mathematically from a list of indicators that are each given the same weight. While Bossel (2001) prefers to use a diagrammatic representation of sustainability (radar diagrams), and both Izac and Swift (1994) and Harger and Meyer (1996) are content to present their results as tables, the ESI is a single number.

The ESI is calculated on a nation-state basis with values for each country varying between 0 (most unsustainable) to 100 (most sustainable). The results are presented as a league table to invoke a sense of name and shame and thus encourage states to improve their performance, and the project has been successful to the extent that the ESI league tables have been widely reported in the popular press and there is some evidence that the high profile of the index has impacted upon national policy.

The methodology for arriving at the ESI is complex and the details need not concern us here. The interested reader can explore the many reports and documents available at [www.ciesin.columbia.edu/indicators/ESI/](http://www.ciesin.columbia.edu/indicators/ESI/). Here, it is only necessary to summarize the main features, and while the approach has been consistent the details do vary across the three published versions of the ESI to date (2001, 2002 and 2005). The indicators included in the ESI are diverse and span some that are obvious, such as the levels of ambient pollution, emissions of pollutants and impacts upon human health, but also response indicators, such as being a signatory to international agreements to limit release of pollutants or conserve biodiversity. It should be noted that while the indicators can be classified using the DSIR framework, it is not explicitly used in the ESI documentation. Instead they prefer to use the headings of:

- environmental systems;
- reducing environmental stresses;
- reducing human vulnerability to environmental stresses;
- societal and institutional capacity to respond to environmental challenges;

- global stewardship.

The first of these (environmental systems) equates largely to state indicators, while the second (reducing environmental stresses) mostly comprises pressure indicators. The other three categories are largely composed of response indicators.

The ESI of 2005 uses data sets for 76 variables, which in themselves can be thought of as indicators. However, the creators of the ESI decided to amalgamate related variables into what they term ‘indicators’ (76 variables into 22 ‘indicators’). Given the range of variables involved, this aggregation is understandably not a straightforward process. The first step is to smooth the data by removing extreme values. If a variable has a highly skewed distribution, then the skew is lessened by taking logarithms, and following this each variable is ‘capped’ to remove extreme values by employing the 97.5 and 2.5 percentiles. Missing data (and there may be many of them with some variables) are handled by a complex process of regression.

Once the variable data are ready for aggregation into the 22 indicators (in the case of ESI 2005), they first have to be standardized. This is achieved by using the mean (average) and standard deviation (a measure of variation in the data) of the variables. If higher values of the variables are deemed to be ‘good’ for sustainability (e.g. biodiversity), then the z value is given by:

$$z \text{ value} = \frac{\text{country value} - \text{mean}}{\text{standard deviation}}$$

If high values are deemed to be bad for sustainability (e.g. emissions of pollutants and reduction in human health), then the z value is given by:

$$z \text{ value} = \frac{\text{mean} - \text{country value}}{\text{standard deviation}}$$

The average z value is then found for each indicator.

Even without going into details, we are sure the reader is getting a sense of the complexity involved in generating the ESI; but this is not yet the end of the manipulations. The average z values (i.e. for the 22 indicators) are converted to a more intuitively meaningful statistic by calculating the ‘standardized normal percentile’, and the result is a set of numbers with a theoretical minimum of 0 and a theoretical maximum of 100. These are, in turn, averaged to yield the ESI. The closer the ESI is to 100, then the better the environmental sustainability for that country.

The ESI is promoted by a powerful group and has been designed to attract attention both in its collapsing of sustainability via a rather complex route to a single number and the league table style of presentation. No other effort to produce a single index for sustainability has arguably had anything like the

success of the ESI, and it can also be argued that the ESI has outdone even the UN lists of SIs in terms of reporting in the popular press. While extensive reporting in the national press may be a good first step in attracting attention and raising awareness, there are some indications that the ESI has had an impact upon policy, although the extent of this and its durability are less known. It also has to be acknowledged that this high profile comes at a price in that many simplifying assumptions have had to be made to pin values to countries. For example, air and water pollution can cross frontiers; indeed, some countries will 'export' dirty and low-wage production to developing countries, thereby exacerbating the variation in the ESI (Lawn, 2007). Also, while the intention is no doubt well meaning, the ESI includes a significant proportion of variables which do not measure environmental quality as such but instead measure what countries are doing about it (e.g. variables that measure involvement in international collaborative efforts and investment in science and technology). There are two problems here. First, there may not necessarily be a cause-effect relationship between environmental quality and the doing of something about it. Second, variables that measure investment in research and facilities will tend to favour the richer countries: those with the resources to invest. However, most important of all is the underlying subjectivity of the ESI presented in a form that implies much objectivity. The methodology summarized above provides but a taste of the technical complexity of the index, and the documentation, while presented in great detail, does not lend itself to easy digestion by a non-specialist. Almost inevitably the tendency is for the 'consumer' of the index and league table to accept their validity and not contemplate how the decisions have been made to include only certain variables. Thus, the ESI is a reflection of what creators at Yale and Colombia universities feel is important for environmental sustainability, and others can and do disagree with these choices and thus create very different country 'rankings'. In 2001, *The Ecologist* journal provided an excellent example of this, and who is to say that its construct is any less valid than that of the Global Leaders of Tomorrow.

It is interesting to note that in all four of the above examples, those who have set the framework are, for the most part, politicians, policy-makers, social or natural scientists. All of the examples are 'top down' and technocratic in nature, and while this is perhaps most obvious with the ESI, it equally applies to the other three examples. Logically, one may feel that those best placed to define sustainability and to set relevant SIs would be the beneficiaries (also referred to as the stakeholders) of the programme. For example, Mitchell et al (1995) state the following as the first principle in the development of SIs:

*Stakeholders [should] reach a consensus on the principles and definitions of sustainable development that are used and the objectives of the sustainability indicators programme.*

However, this has rarely been put into practice, and for the most part the SIs, or at least the methodology for developing SIs, have been set by outsiders, with perhaps a nod in the direction of those whom the SIs are ultimately meant to serve. Indeed, is sustainability really an important consideration for all stakeholders, and if it isn't, should an outsider impose it? The following comment by Tisdell (1996) related to agricultural sustainability is very sobering: 'In fact, sustainability is unlikely to be an overriding consideration of a farmer from an economic viewpoint.'

Given that participation has been central to much development since the late 1970s, particularly in terms of guiding research priorities, and the fact that a huge and highly accessible literature has grown around the subject (see Chambers, 1981, 1991 and 1997; Chambers et al, 1989; Scoones and Thompson, 1994), it is interesting how the 'sustainable' part of sustainable development has retained such a top-down and Western emphasis. The issue of participation in sustainability, and particularly in the development of an SI framework, is, we believe, of paramount importance and will be returned to in greater depth in Chapters 5 and 6.

Another issue is the way in which the indicators/indices have been presented for consumption by 'users'. To a large extent, this would depend upon who the consumer is meant to be and the four examples provide a quite different set of perspectives. At one extreme, some have attempted to encapsulate SIs using an appropriate weighting scheme into a single measure of sustainability, as illustrated with the ESI. There are other examples in similar vein, such as the degree of sustainable development (DSD) suggested by Niu et al (1993). Another, perhaps more focused, example is the use of an economic approach for measuring sustainability called Total Factor Productivity (TFP). TFP attempts to measure an efficiency of production by including all of the costs, even ones which are perhaps not so obvious. A classic application of TFP is in agriculture (see Box 1.7). It is, of course, possible to include the costs of fertilizer purchased in bags; but what about the nutrients already present in the soil and which the farmer has not paid for? Effectively, they can be regarded as 'free'; but mining these nutrients would mean that the farmer has to apply more fertilizer to get the same yields. Another example is the influence of rainfall. Farmers do not 'buy' rain, although they can invest in irrigation; but it is clearly an important factor in production. TFP attempts to account economically for all of these 'hidden' factors.

The notion of a numeric value for sustainability such as the ESI is attractive for the very reason that the Shannon–Wiener biodiversity index, and others like it, is attractive. Simplifying system complexity into single values that allow for easy comparison has a definite appeal, and this has been particularly exploited with the ESI in parallel with the use of country league tables. Others have sought to keep the richness of sustainability intact by using various tabular or diagrammatic formats, and the 'radar' diagrams of Bossel (2001) are an example. A variant on the 'radar' form of diagram is the AMOEBA of Gilbert (1996) and others (a general method for ecosystem description and assess-

**Box 1.7 The theory behind the calculation of the  
Total Factor Productivity Index (TFP) of sustainability  
in tropical farming systems**

Lynam and Herdt (1989) define the TFP as:

$$\text{TFP} = \frac{\text{value of outputs from farming system}}{\text{value of inputs into farming system}}$$

Lynam and Herdt (1989) suggest that changes in TFP over time equate to a measure of sustainability (i.e. change in productive capacity of the system). In its simplest form:

Increase in TFP = sustainability

Decrease in TFP = unsustainability (decline in resource base).

Tisdell (1996) suggests a slight modification of this idea to focus instead on profitability (P) of the system:

$$\text{TFP} = \frac{\text{value of output} - \text{value of input}}{\text{value of input}}$$

This is fundamentally an economic approach based on the productivity of the farming system, and works as long as inputs (including the natural resource base) and outputs can be given a monetary value. Other environmental and social effects that many consider central to sustainability are not included.

ment), which is described in Chapter 2. In some cases, the SIs are superimposed on maps of the area to illustrate how they vary over space. This may become more common with the increasing use and power of geographic information systems (GIS) on microcomputers.

Although a single SI may be relatively easy to interpret provided that one has a clear reference point, the interpretation of a suite of SIs may be problematic. What does one conclude if some are within the reference limits and some are not? Does one take an all or nothing point of view (the 'binary' view of sustainability – either a system is sustainable or not), or can one conceive of gradations of sustainability? Also, if SIs are taken over a period of time, they can be used to determine a trend – do they stay the same, increase or decrease, and, if so, by what rate? In a sense, the absolute values of the SI may not matter (just as well if it is based on 'guesstimates'!). Instead, the emphasis is on how they change with time. The problem is what happens if the trends for different SIs within a matrix go in opposite directions (see Figure 1.2c) – some stay the same while others go up and down. Furthermore, what if the same SI shows a complex pattern of increases and decreases with time as in Figures 1.2b and 1.3? In addition, although the trends can be useful to illustrate sustainability, they need to be combined with estimates of what is acceptable. After all,

sustainability can be achieved at a very low level of system quality; but is the low level acceptable? Single values of SIs with units require some sort of baseline for interpretation. A value of X units is meaningless unless we have an idea of what range equates to sustainability or, in other words, what represents the target or reference condition. This is not easy! Jansen et al (1995) were able to establish limits to nutrient balances that reflect sustainability; however, for the biocide index mentioned earlier: 'No clear-cut relation exists between the calculated index of biocide use and the sustainability of the system, making calculation of a limit to the biocide index impossible.' Instead, a limit to the biocide index equating to sustainability could only be set 'subjectively'.

Once a set of SIs has been agreed upon, they have to be measured. The fewer the SIs to be considered, the easier this may be, although the tendency may be to include a large number of SIs in order to cover the breadth of sustainability.

Obtaining the value of an SI may be a relatively easy task if good-quality data is already available, or if the means of getting such data is already well established. Indeed, the availability of relevant data may not be a problem at all, and all the difficulties will revolve around choice, interpretation and use of SIs:

*In the developed world, we often have far more data than we can ever use. In most cases, what is lacking is not data but an understanding of what is important and the resolve to act. (Lawrence, 1997)*

If new data has to be collected, then the precise methodology for determining an SI will, of course, depend upon what it is. For example, in the Izac and Swift (1994) set of SIs, the soil nutrient status, organic matter content, water-holding capacity, and the abundance of an animal or plant species can be determined by employing standard analytical and ecological sampling techniques. Clearly, there is the problem of variation, given that in the same field there can be marked differences in, for instance, nutrient status within very short distances depending upon slope, previous cultivation and the presence of trees or termite nests; however, given the resources, these problems are resolvable. The same would be true of water and air quality, once it is agreed what properties to measure. Issues surrounding social welfare and economic efficiency can also be assessed using standard social science surveying techniques. It should be noted, however, that although many of these tools are well established, they are not without limitations. For example, monitoring carbon monoxide levels may be a reasonable indicator of air quality; but this can vary dramatically within a short distance and during a day, let alone due to weather effects. Monitoring can be expensive; hence, the typical approach is to place monitoring stations at places which are prone to greatest risk – for example, near busy road junctions. But can the data from but a few stations be extrapolated to represent air quality for a whole town?

## **Sustainability indicators: A realistic and reasonable approach to measuring sustainability?**

As one may construe from all of the foregoing, the selection and measurement of SIs is hardly a fine art and is subject to many pressures, agendas and biases. Governments often wish to portray themselves in the best possible light, and it is certainly not hard to imagine that ‘reference’ conditions may be set with a political agenda in mind. Indeed, given all of the above, the reader could be forgiven for thinking that the development and application of SIs as a way of gauging system sustainability may be unrealistic. There are a number of critics of SIs, and the following two chapters will illustrate some of the major planks upon which these criticisms are based. It should first be noted that the problems discussed so far in this chapter, including defining sustainability, and the setting of spatial and time scales, are well known to the proponents of SIs; as has already been illustrated, workers in the field attempt to provide various solutions.

One of the major criticisms regarding SIs is that they attempt to encapsulate complex and diverse processes in a relatively few simple measures. This is not a new problem. The world is a complex place, and people have had to make sense of it for a long time! The obvious approach is to deal with the world in manageable bits. Scientists deal with a complex system by breaking it down into its components and studying how they work in isolation and then together; this is the reductionist approach. Reductionism has received much criticism by authors (Capra, 1982, 1996, 2004) on the reasonable basis that some systems are so complex, with millions of interactions, that we are unable to look at every one. However, do we need to? Biologists have been dealing with complex ecosystems for many years, and they have long used indicators as a tool for gauging ecosystem health. Their experience suggests that:

*The number of possible interactions among species is astronomical. If ecosystems science is strictly a study of species interactions, it is hopelessly complex. But just as we need not consider all cell-to-cell interactions whenever we discuss a single organism, so we need not consider all possible species-to-species interactions whenever we discuss ecosystems. (Slobodkin, 1994)*

Allied to reductionism is a common perception that scientists, policy-makers and others are obsessed with quantification. The distillation of information on biodiversity into a single value such as the Shannon–Wiener Index is only one example of quantification; but all four examples of SIs given above are number based. Interestingly, some argue that belief in quantification is itself generated and reinforced by paradigms; this, in turn, requires proof of the wider application of a paradigm. In other words, the evolution of sustainability

as a paradigm inevitably leads to a need to quantify sustainability; hence, sustainability indicators were developed as a means of keeping the paradigm alive. Quantification, however, does have limitations, and clearly it is not possible to measure all human experience. Indeed, for all their attempt at holism (see, for example, the second Bellagio principle) and a desire to incorporate the richness of humankind's complex interrelationships with nature, SIs are still a classic reductionist set of tools based on quantification. Indeed, we find it very ironic that those who scorn attempts to give value to sustainability, or to produce tables of SIs such as those proposed by the UN, still employ a language that has quantification at its heart. This has clear relevance; indeed, we feel it is central to the whole sustainability debate. Can we really use simple SIs to gauge such a complex issue as sustainability? Although aware of these pitfalls, many, of course, do just that. As Harrington (1992a) points out: 'it is never possible to deal with any problem (not just sustainability problems) in all its real-world complexity'. Scientists 'have to simplify to survive'. But how much simplification is acceptable? Clearly there is a trade-off between necessary simplification and at the same time having SIs that are meaningful. However, this is not a problem unique to sustainability or, indeed, to ecology. As Slobodkin (1994) states:

*Any simplification limits our capacity to draw conclusions, but this is by no means unique to ecology. Essentially, all science is the study of either very small bits of reality or simplified surrogates for complex whole systems. How we simplify can be critical. Careless simplification leads to misleading simplistic conclusions.*

Harrington (1992a and 1992b) rejects the notion that quantifying sustainability is not possible precisely because it has been successfully achieved with complex biological systems. After all, what about the species indicators and biodiversity measures described earlier in this chapter? Farming systems research has also provided a wealth of experience in dealing with complex systems. Indeed, here is the nub! If the development and application of SIs were purely an academic exercise with no real immediate and practical relevance, then one may be willing to accept initial problems of oversimplification as an essential and necessary part of a lengthy learning curve. It should be remembered that ecologists and agriculturalists can make predictions about system behaviour based on their knowledge of the system's components and their interactions. If the results do not match reality, it is back to the drawing board for refinement. Ecology is a science, and like all science any predictions (hypotheses or models) are compared to the hard reality of what actually happens. If the predictions fail, then a good scientist will acknowledge the fact and build this new knowledge into future predictions. The result is an evolving body of knowledge accumulated over many years by a rich process of hypothesis formulation and testing.

While it is true that ecologists are part of a wider society, and are not isolated from socio-economic, cultural and political pressures that set priorities for research and how results are used, the science itself should be immune to these pressures. Similarly, farming systems research (FSR, also sometimes referred to as farming systems research and extension – FSR/E – or, more generically, on-farm research) combines a systems framework of analysis with research in which the farmers and their families play a central role in the process (McNamara and Morse, 1996). The language is certainly similar to that of sustainability – holism, systems perspective, incorporation of social perspectives and methodologies are all central to FSR. However, the setting of hypotheses, and testing, acceptance or rejection are also a part of the FSR process, albeit under different guises and by different means than in ecological science.

Does the development and use of SIs parallel the scientific approach of ecology, or even FSR? Frankly, it does not since the sustainability–SI combination involves a degree of circularity. Sustainability itself is a human vision that by definition is laced with human values (political and ethical) and SIs are not necessarily developed through a long process of hypothesis setting and testing, intended to arrive at a deeper understanding of sustainability. Granted, an element of refinement can be built in; but one does not develop a host of SIs, then ‘test’ them to see whether they adequately describe sustainability. Rather, the starting point is a description of sustainability, with all of its human subjectivity, followed by an identification of SIs to gauge attainment of that description. Indeed, if we are planning to make major policy and economic changes to a system in order to get the SIs moving in the right direction, we do not want the SIs to be continually changing while all of this is happening. Not only can confusion result, but one is left open to the charge of changing SIs to suit. The reader should not take this to mean that SI selection is somehow inferior to more rigorous approaches in science. It is not inferior, but different.

An additional and very important factor is the role of those involved in setting agendas and the provision of funding for development initiatives. Money is inevitably a scarce commodity, and phrases such as value for money, cost effectiveness, project appraisal and evaluation are commonly employed by funding agencies. Given this background, donor agencies have become concerned about the sustainability of organizations charged with development in the field, as well as the sustainability of the outcomes of development. These two visions of sustainability are quite different and not necessarily complementary. An excessive emphasis on the sustainability of the method may inevitably result in less emphasis on the sustainability of the final outcome.

In the next two chapters we examine some of these two concerns in greater depth. In order to do this we describe SIs at a number of levels. To begin with, we illustrate the limitations of the reductionist, mechanistic and quantitative approach to sustainability by looking at some of the ecological ideas behind one SI recommended by the UN: the maximum sustainable yield in fishery management. This is followed by a description of an attempt to forge different

SIs together into one overall picture of sustainability – the AMOEBA approach. Since both MSY and AMOEBA are essentially located in natural resource management, we examine how holism in sustainability (combining environmental, social and economic concerns) is attempted by focusing on the use of SIs in sustainable city programmes. Finally, we discuss some of the points that arise out of the need for agencies to appraise field projects on the basis of sustainability. The example chosen is the expanding area of financial service provision in developing countries.

It should be stressed that sustainability and SIs cover a huge amount of ground, and the examples selected for Chapters 2 and 3 should not be read as implying that these are the only ones or, indeed, are necessarily the best. Our aim, instead, is to choose areas that link to debates in later chapters and, hence, are illustrative of general principles rather than specifics.

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