The Sustainability Revolution: A scientific analysis of beneficial changes for societies, communities, and individuals

Chapter One: Principles

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This is the first of 15 chapters of a book I am writing on Sustainability. I'd appreciate any comments or suggestions that would help me improve the manuscript.

Part I: Principles

Sustainably Meeting Human Needs

Consider a fanciful retelling of the story of Adam and Eve that parallels the true plight of modern humanity: When Adam and Eve ate from the Tree of Knowledge, they gained not only knowledge but also an insatiable appetite. They used their knowledge to harvest all of the resources in the Garden of Eden and built a large mansion to isolate them from nature. Eden, which had supplied all of their needs, eventually became a wasteland. Because they failed to act as good stewards of nature as God commanded, and instead consumed all of the resources, they lost their home and were forced to move to more marginal lands to survive. God did not command them to leave Eden; they left because they had destroyed Eden, making life there unsustainable.

The concept of sustainability was ill-defined until 1987, when the U.N. World Commission on Environment published "Our Common Future." The report is often referred to as the "Brundtland Report" because the Norwegian prime minister Gro Harlem Brundtland chaired the Commission (WCED 1987). The authors defined sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their needs (Dresner 2008)." It therefore emphasized intragenerational and intergenerational equity. To better understand sustainable development we need to examine human needs and how to meet them.

For a better future, we must design a society that meets our needs. And what are those needs? The most famous elaboration is Abraham Maslow's hierarchy of needs (Figure 1). Maslow believed that humans are happy when these needs are met. He listed the needs in order of priority. Humans must first fill their basic "physiological" needs shown at the bottom of the pyramid, and then provide for "safety." Meeting these needs makes it more likely that a human will survive long enough to fill the next need of "love/belonging," which makes it more likely that they will propagate their genes. Because natural selection does not operate at levels higher than love/belonging, many people do not progress to "esteem" and finally "self-actualization," which is defined as a person meeting their full potential. A sustainable society would give people the opportunity to become "self-actualized", to meet their full potential.

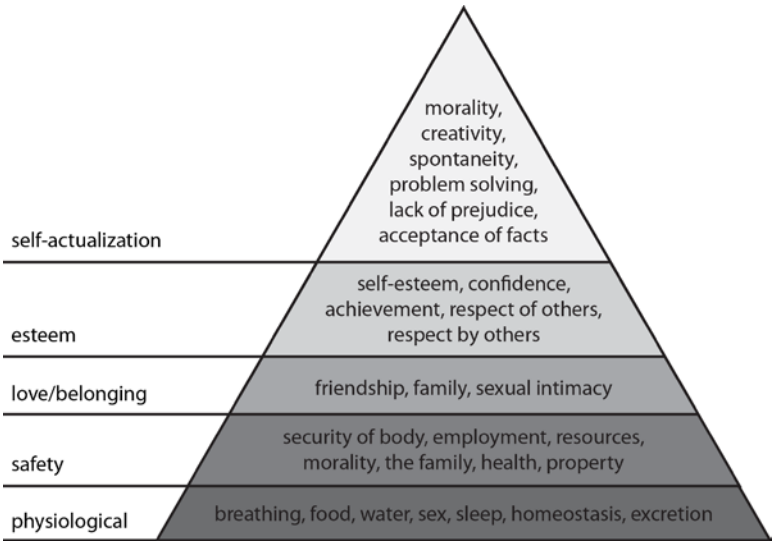


Figure 1. Maslow's hierarchy of needs, with the most basic needs at the bottom.

More recently, Chilean economist Manfred Max-Neef argued that humans do not meet needs sequentially or hierarchically. Max-Neef lists the fundamental human needs as subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom. He argues that a poverty arises whenever one of these needs is not met. Some examples are: poverty of subsistence (due to insufficient income, food, shelter, etc.), of understanding (due to poor quality of education), and of participation (due to discrimination against women, children, and minorities). Max-Neef considers the way a culture meets needs a defining aspect of that culture ((Wann 2007), pp. 165-8). Max-Neef's model is more appropriate than Maslow's for understanding development in the developing world and how to make it sustainable.

Table 1.1 Human Scale Development:
Max-Neef's Classification of Fundamental Human Needs[i]

Fundamental Human Needs	Being (qualities)	Having (things)	Doing (actions)	Interacting (settings)
subsistence	physical and mental health	food, shelter work	feed, clothe, rest, work	living environment, social setting
protection	care, adaptability autonomy	social security, health systems, work	co-operate, plan, take care of, help	social environment, dwelling
affection	respect, sense of humour, generosity, sensuality	friendships, family, relationships with nature	share, take care of, make love, express emotions	privacy, intimate spaces of togetherness
understanding	critical capacity, curiosity, intuition	literature, teachers, policies educational	analyse, study, meditate investigate,	schools, families universities, communities,
participation	receptiveness, dedication, sense of humour	responsibilities, duties, work, rights	cooperate, dissent, express opinions	associations, parties, churches, neighbourhoods
leisure	imagination, tranquillity spontaneity	games, parties, peace of mind	day-dream, remember, relax, have fun	landscapes, intimate spaces, places to be alone
creation	imagination, boldness, inventiveness, curiosity	abilities, skills, work, techniques	invent, build, design, work, compose, interpret	spaces for expression, workshops, audiences
identity	sense of belonging, self-esteem, consistency	language, religions, work, customs, values, norms	get to know oneself, grow, commit oneself	places one belongs to, everyday settings
freedom	autonomy, passion, self-esteem, open-mindedness	equal rights	dissent, choose, run risks, develop awareness	anywhere

Society has been ineffective at meeting human needs. Partly this is due to confusion between *needs* and *wants*. It also results from the incorrect assumption that economic growth alone will meet everyone's needs. If societies and governments redefine their primary objective as meeting human needs, and stay focused on that objective, success will follow. As noted by Wann ((2007), pp. 159-60), "we should rely on efficiency (no waste), sufficiency (the right amount), and design (the right stuff) to meet needs directly." If societies learn how to meet needs precisely, without waste, then human well-being and happiness will increase and society will become more sustainable.

Sustainability and Human Well-Being

We can also discuss sustainability in terms of human well-being. According to the UNEP GEO-4 report (UNEP 2007), "Human well-being is the extent to which individuals have the ability and the opportunity to live the kinds of lives they have reason to value... Human well-being encompasses personal and environmental security, access to materials for a good life, good health and good social relations, all of which are closely related to each other, and underlie the freedom to make choices and take action." The Global Footprint Network (GFN 2009) states that "The essence of sustainability is a commitment to human well-being – well-being that lasts." Thus, to understand sustainability, we must first understand the nature of human wellbeing.

One view is that human wellbeing is correlated with the degree of fulfillment of human needs. The further up Maslow's hierarchy of needs we rise, or the greater the number of Max-Neef's fundamental human needs we fulfill, the greater our wellbeing and happiness. While the Brundtland report defines sustainability in terms of meeting human needs now and in the future, the Global Footprint Network defines it in terms of human wellbeing, as does the Stiglitz report (2009): "The report distinguishes between an assessment of current well-being and an assessment of sustainability, whether this can last over time. Current well-being has to do with both economic resources, such as income, and with non-economic aspects of peoples' life (what they do and what they can do, how they feel, and the natural environment they live in). Whether these levels of well-being can be sustained over time depends on whether stocks of capital that matter for our lives (natural, physical, human, social) are passed on to future generations." Thinking in terms of sustainability forces people to think longer term and avoid making the mistakes that short-term thinking often leads to.

The Stiglitz report (2009) continues: "Another key message, and unifying theme of the report, is that the time is ripe for our measurement system to shift emphasis from measuring economic production to measuring people's well-being. And measures of well-being should be put in a context of sustainability.

Emphasizing well-being is important because there appears to be an increasing gap between the information contained in aggregate GDP data and what counts for common people's well-being. This means working towards the development of a statistical system that complements measures of market activity by measures centered on people's well-being and by measures that capture sustainability.

To define what well-being means a multidimensional definition has to be used. Based on academic research and a number of concrete initiatives developed around the world, the Commission has identified the following key dimensions that should be taken into account. At least in principle, these dimensions should be considered simultaneously:

i. Material living standards (income, consumption and wealth);
ii. Health;
iii. Education;
iv. Personal activities including work
v. Political voice and governance;
vi. Social connections and relationships;
vii. Environment (present and future conditions);
viii. Insecurity, of an economic as well as a physical nature.

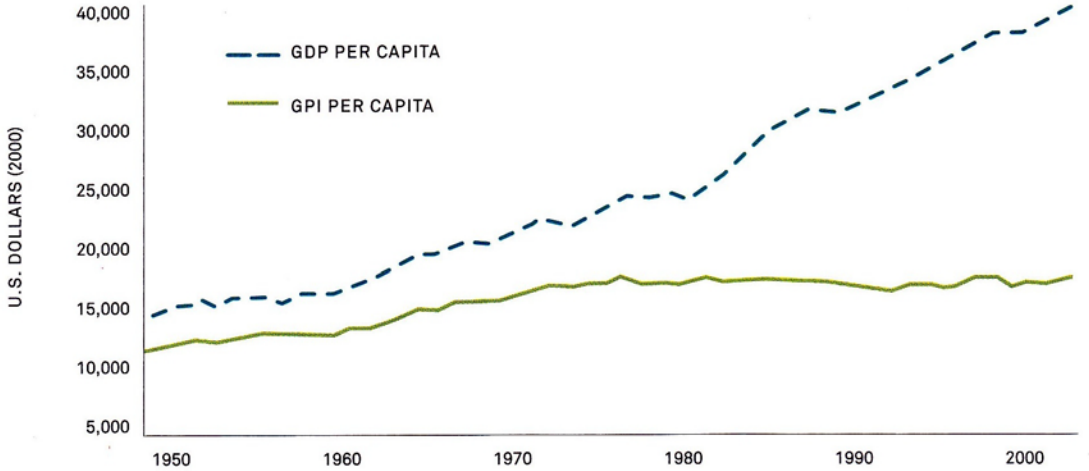
All these dimensions shape people's well-being, and yet many of them are missed by conventional income measures."

Several measurement indicators are used to measure human wellbeing and happiness. The Genuine Progress Indicator (GPI), which replaced the Index of Sustainable Economic Welfare (ISEW), measures "the sustainability of income and the socioeconomic wellbeing of a nation" [ii]. The Human Development Index (HDI), developed by the United Nations Development Program (UNDP), is the most widely used measure of wellbeing in a country[iii]. It takes into account progress in life expectancy, education, and standard of living as measured by GDP. Another useful measure is the Happy Planet Index (HPI), created in 2006 by the New Economics Foundation as "an innovative measure that shows the ecological efficiency with which human well-being is created around the world.[iv]" The HPI measures the environmental efficiency of supporting well-being in a given country[v]. Finally, the Human Wellbeing Index HWI is an average of indices of health and population (H), Wealth (W), Knowledge (K), Community (C), and Equity (E). According to Prescott-Allen, a sustainable country must have a high HWI, meaning that it has the following features ((Prescott-Allen 2001), pp. 13-14):

Table 1.2: A High Human Wellbeing Index Means...

Health	People enjoy long lives in good health...
Population	...while keeping their numbers within the bounds of human and natural resources.
Household wealth	Individuals and households have the material goods and income to secure basic needs and decent livelihoods,
National wealth	and the community has the resources to support and maintain prosperity.
Knowledge	People have the knowledge to innovate and cope with change, live well and sustainably, and fulfill their potential,
Culture	with avenues for spiritual growth, creativity, and self-expression.
Freedom and governance	Human rights are fully respected, and individuals are free to choose how decisions are made and who should make them. Decision-making bodies are open, clean, and effective.
Peace and order	Communities coexist peacefully and protect their members from crime and violence.
Household equity	Benefits and burdens are shared fairly among households and groups...
Gender equity	...and between males and females

A common mistake is to equate human progress with economic growth, typically measured as Gross Domestic Product (GDP). (Figure 2) (from (Gore 2009)) shows that the Genuine Progress Indicator (GPI) correlated with GDP per capita until roughly 1978, when the latter reached about $25,000 U.S. dollars (2000). However, since 1978, the GPI has remained relatively fixed despite significant increases in GDP per capita. Other indicators of human progress such as "percentage of people who are very happy" also no longer correlate well with GDP (Speth 2008), suggesting that increasing economic wealth increases human wellbeing only to a certain point.



SOURCE: Robert Costanza, et. al., *The Pardee Papers*, No. 4, January 2009

Figure 2. From Gore (2009): Whereas GDP is the standard measure of a country's economic performance, summing the market value of all goods and services, the genuine progress indicator (GPI)

is an attempt to measure the sustainability of income and the socioeconomic wellbeing of a nation. GPI adjusts the personal consumption data of GDP by adding the benefits of non-market work, like unpaid housework and volunteering, and subtracting social costs like crime, air and water pollution, and the loss of farmland and forests. Over the last 50 years, GPI has increased at a much lower rate than GDP.

What is Sustainability?

There is enough in the world for everyone's need, but not enough for everyone's greed. –Frank Buchman, founder of the Oxford Group

I know of no restorative of heart, body, and soul more effective against hopelessness than the restoration of the Earth. Barry Lopez in "Helping Nature Heal"

The U.S. National Science Board (NSB, 2009) defines sustainability as "meeting present needs without compromising the ability of future generations to meet their own needs. The definition of 'sustainability' used in this report is derived from the definition of 'sustainable development' in the 1987 report of the United Nations World Commission on Environment and Development." Sustainability is about living within your means, but more importantly living within the means of everyone. This definition of sustainability is adequate for most purposes, but for a scientific analysis of sustainability we must be more rigorous. Here we define the sustainable state of a system as one that we can sustain indefinitely; this is characterized as a steady state in which the amounts of capital of various types (economic, environmental, and social) remain unchanged because inputs equal outputs. Sustainability is a balance between supply and demand, between production and consumption. When the amount of resources we consume equals the amount we produce, we are "net zero." For example, a home is sustainable if it consumes no more resources than it produces, i.e., it is net zero for energy, water, and food.

To achieve sustainability, we must not only achieve a balance between supply and demand (inflows and outflows), but also decrease the waste produced so as not to exceed the waste absorption capacity of the environment. Thus, we must also apply the "net zero" concept to waste and strive to produce zero waste. We must produce as much resource as we consume, and we must consume as much waste as we produce. We can consume waste by treating it as a resource and finding ways to use it.

In a sustainable state, resources such as food or water are always available. Thus, a sustainable state is also the state of minimum risk to current and future generations. Sustainable living reduces insecurity for individuals and their offspring. We can never eliminate insecurity, but we can greatly reduce it by reducing the probability of running out of essential resources (food, water, and energy) and of being exposed to a harmful environment. Sustainability reduces many types of risk related to the economy, global climate change, pollution, natural hazards, and availability of food, water, and energy.

True sustainability also requires zero growth of population and the economy. The scientific term for this is a 'steady state' where inputs equal outputs. For example, zero population growth requires that the birth rate equal the death rate. Organization such as The Center for the Advancement of the Steady State Economy (http://steadystate.org/) advocate for the slowing of economic growth, which depletes natural resources and causes environmental degradation, in some cases to such a degree that human wellbeing is diminished.

In common use the word development is taken to mean economic growth, but economic growth cannot be maintained indefinitely in a world with finite resources and space. This type of sustainable development is preferable to unsustainable development, but it cannot create sustainability (Ehrenfeld 2008). It can point us toward the Promised Land, but it can't get us all the way there (much like Moses). On the other hand, if 'development' refers to human and social development, then sustainable development can create a sustainable state. The Brundtland commission used 'development' in this sense, since they discussed sustainable development in terms of meeting human needs. Let me emphasize that sustainable development improves the human condition by meeting human needs in both the short and long term, but it is truly sustainable only if it does so without growth.

Besides ceasing unsustainable practices that are wasteful, inefficient, or harmful to society, the economy, or the environment, we must create new, sustainable practices. McDonough and Braungart explain this concept in their influential book "Cradle to Cradle" (McDonough and Braungart 2002). They argue that we can do more than just reduce pollution and waste. We must also create positive effects, and move from being "eco-efficient to eco-effective." McDonough and Braungart (McDonough and Braungart 2002) encourage businesses to use sustainable design to make products that will enhance economic, environmental, and social health. Products should be biodegradable, so that at the end of their life cycles they will become food instead of waste. Microorganisms can convert waste into the valuable resource soil and save landfill space. This is true

recycling, not simply “downcycling” where we recycle the product into a degraded form. The Cradle to Cradle (C2C) approach also advocates that we design human industrial systems to mimic natural cycles in which nutrients (resources or materials) safely circulate in closed loops.

The three components of sustainability (Figure 3) are Social, Economic, and Environmental (or the equivalent three P's: People, Prosperity, and the Planet). A more accurate figure makes clear that in fact the economy is a subset of society, which is a subset of the environment (Figure 4). We cannot have a healthy, sustainable economy without a sustainable society, which in turn requires a sustainable environment.

Figure 3. Fig. 1.1: The three spheres of sustainability.

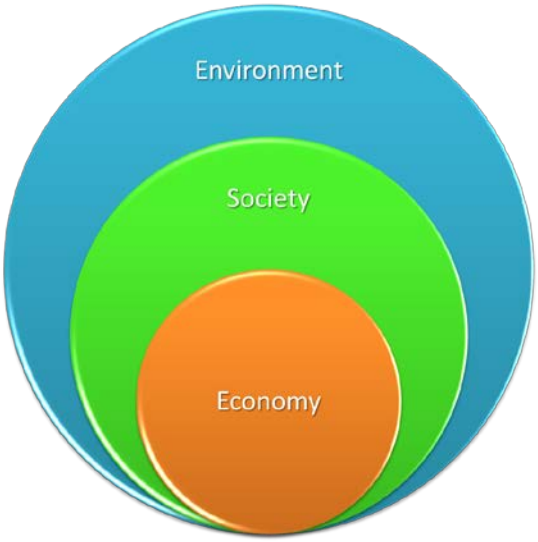


Figure 4. The nested spheres of sustainability.

Current policies emphasize the economic component over social and environmental. "This is a major reason why the environment continues to be degraded and development does not achieve desirable equity goals. The three 'pillars' cannot be treated as if equivalent. First, the economy is an institution that emerges from society...The environment is different, since it is not created by society. Thinking about tradeoffs rarely acknowledges this. Second, the environment underpins both society and economy (Adams 2006)."

The global economy and human population are increasing in size at an exponential rate (see Chapters 2 and 3). Exponential rates of change of any kind are unsustainable and lead to unstable systems. To achieve sustainability we must slow the rate of growth of the economy and population and engage in sustainable development, which will allow us to leave future generations the capacity to live as well as we do today (Brundtlandt Commission).

To meet present needs without compromising the ability of future generations to meet their own needs, we must preserve economic, environmental, and social capital (see definitions below) for future generations. Preserving capital requires increasing economic, environmental, and social security. Keeping the rate of consumption (demand) less than or equal to the rate of production (supply) preserves capital because capital increases or remains constant over time[vi]. We can use **triple bottom line accounting,** also known as **sustainability accounting,** to keep track of all three forms of capital and to identify sustainable purchasing and policy options. We can achieve sustainability through conservation and efficient use of capital, building up of capital reserves, using triple bottom line accounting, and diversifying by adding redundancy to capital supply systems (e.g., have multiple sources of food, water, and energy). We will explore these strategies throughout this book.

Social, economic, and environmental sustainability require that society preserve or increase the amounts of social, economic, and environmental capital defined as follows (modified from (Dodds 2008)):

Social capital includes human, social, and institutional capital. "Human capital includes the health, skills and knowledge embodied in people, and the physical ability to do work. Human capital can be enhanced through education and training, and through improved nutrition and physical and mental health. Social and institutional capital includes networks of relationships between people, rules and governance arrangements, and shared norms and culture. Social capital contributes to well-being directly, such as through relationships and sense of identity. It also has an important role in facilitating the coordination and use of other forms of capital to promote human well-being." Institutions such as employers or the government can preserve or increase social capital by providing support services such as childcare, counseling, and rehabilitation of criminals.

Economic capital (often called "Produced" capital, which is sometimes split into physical and financial capital) "includes tools and equipment, buildings, books, vehicles, and physical infrastructure such as roads, bridges, pipes and power lines. This group also includes financial assets and access to credit and insurance, which are essential components of household livelihood strategies and regional or national development success."

Environmental capital "includes all environmental resources and processes that provide value to people, such as food, fiber, clean air and water, energy and waste processing. It also includes non-renewable resources, such as minerals, oil and coal."

Sustainable strategies maintain all three types of capital through effective use, protection, and diversification of assets[vii]. For example, among other things social sustainability means building and preserving effective social institutions such as schools and hospitals that help provide an educated and healthy workforce, using that workforce as a resource by providing jobs, and encouraging social interactions that build communities, which enhance security by acting as safety nets. Economic sustainability means a zero-growth economy that equitably provides the resources required to enjoy a healthy, productive life. Environmental sustainability means preserving biodiversity and therefore ecosystem services that future generations will need to maintain our quality of life.

Can we be sustainable by growing or preserving capital in only one or two of the three components of sustainability? As an example of building economic capital without social capital, I relate the true story of a Nashville foreman who saved all of his money but was not on speaking terms with any of his family. When he died he left $600,000 in a trust for a Children's home, but because he had no one who was close to him to administer the trust he appointed an acquaintance as the executor. That person turned out to be a con man who squandered the money, leaving the Children's home only $50,000. To be sustainable, individuals and society must build or preserve capital in all three areas of sustainability, economic, social, and environmental. Building only one or two legs of a three-legged stool results in an unstable stool.

Here we must recognize and define two types of sustainability: weak and strong. *Weak sustainability* assumes that substituting one form of capital for another is possible, i.e., we can compensate for a reduction in one type of capital (typically reduced environmental capital) with an increase in another type of capital (typically produced capital). This approach measures sustainability using the total value of the aggregate capital stock, i.e., the combined values of economic, social, and environmental capital. In contrast, *strong*

sustainability argues that substitution is not always possible between different types of capital, and therefore that we must maintain economic, social, and environmental capital independently (Ott 2003). For example, economic capital cannot necessarily substitute for social or natural capital; some ecosystem services cannot be replaced. Also, loss of social and environmental capital may be irreversible: for instance, once a species goes extinct, it is lost forever. Some components of ecosystems like coral reefs cannot be removed without collapse of the entire ecosystem. A coral reef is an example of *critical natural capital*, since no other form of capital can substitute for it (Adams 2006)." According to Ott (2003) "Many economists now accept that a minimum stock of natural capital is critical for human survival and well-being. If so, weak sustainability needs to integrate a notion of critical natural capital, including criteria for its determination... But if economists accept the necessity of critical natural capital, they implicitly drop the assumption of unlimited substitutability." The precautionary principle and the minmax principle (strategy for minimizing potential loss while maximizing potential gain) both argue for strong sustainability (Ott 2003). Thus, in this book we advocate strong sustainability, in which sustainable development and sustainable maintenance require that we balance the books independently for all three components of sustainability. Sustainable development requires managing all three types of capital (social, economic, and environmental) so that all three increase or remain constant in size.

This book will primarily focus on the sustainability of human societies, especially at the small scale of families and communities. That is what we are most familiar with, and it is where we have the most influence and can take personal action. However, we cannot maintain human society without also preserving our supporting ecosystems and their biological diversity, because we depend on those ecosystems to provide our food, water, air, and medicines. In short, ecosystems provide many life-support functions that we take for granted. Without those ecosystems, we would likely perish. Fortunately, most of the solutions for preserving human society also help to preserve our supporting ecosystems. Unsustainable practices that our society should abolish in order to become sustainable include:

Table 1.3: Examples of unsustainable practices

- Use of disposable products
- Use of inefficient products
- Deficit spending
- Reliance on nonrenewable resources such as oil
- Overuse of renewable resources such as water
- Polluting the air, water, or soil by using synthetic chemicals
- Planning development without considering environmental impacts
- Focusing only on growth of economic capital while ignoring social and environmental capital
- Wasting food, water, or energy

When all of the members of a society adopt a sustainable lifestyle, the society will become sustainable. A sustainable society maximizes and maintains social, economic, and environmental capital. It increases security and survival rates - and therefore longevities - by securing multiple reliable, sustainable sources of water, food, and energy. It is a community that conserves these resources and uses them efficiently. These actions make the community autonomous and self-reliant. Throughout this book we will examine strategies for effectively using, protecting, and diversifying social, economic, and environmental capital to increase security.

Capital Supply and Demand

Every form of capital consists of a nonrenewable portion termed 'principal' and a renewable portion termed 'interest.' To protect social, economic, and environmental capital, society must rely only on the interest and not the principal in each category. The interest is the renewable portion, and the rate of its use shouldn't be greater than the rate of renewal. Fiscal conservatives use this approach to achieve economic sustainability. Relying on renewable resources (interest) rather than non-renewable resources (principle) allows us to achieve both economic and environmental sustainability.

Table 1.4: Sustainable Use of Renewable Resources[viii]

Consumption of renewable resources	State of environment	Sustainability
1) More than nature's ability to replenish	Environmental degradation	Not sustainable
2) Equal to nature's ability to replenish	Environmental equilibrium	Steady state
3) Less than nature's ability to replenish	Environmental renewal	Environmentally sustainable

Since human population is growing at an exponential rate, our rate of capital use is also increasing at an exponential rate. This is sustainable only if growth does not cause the rate of capital consumption to exceed the rate of capital production, i.e., the rate of replenishment. For example, if we are talking about a form of environmental capital such as a renewable resource (Table 1.4), society usually begins in a state where the rate of consumption is less than the rate of replenishment (category 3). Eventually, the population becomes so large that humans reach a steady state and consume the resource at the same rate they produce it (category 2). In this state – the optimal one, as it allows the greatest number of people to live sustainably - supply and demand are in equilibrium because they are equal. If the time rates of change of supply and demand are not equal, this state will be temporary. For example, if the population and the rate of resource consumption continue to increase, and if the rate of replenishment (which is usually constant) cannot keep up with increasing consumption, the system will become unsustainable, leading to environmental degradation, loss of environmental capital, and resource shortages (category 1). We'll show later that humanity began using renewable resources faster than they could be replenished beginning in the 1970's, and the imbalance has continued to grow since that time.

In a sustainable system supply exceeds or equals demand indefinitely. We can maintain a sustainable state only if supply ≥ demand and the time rate of change of supply ≥ that for demand. Usually the rate of replenishment of renewable resources is fixed, so the time rate of change of supply equals zero, and therefore in a sustainable state the time rate of change of demand must equal zero.

Let's look at water in a lake as an example (Figure 5). The stock of water is the amount of water stored in the lake. Inflow is a measure of supply, i.e., the rate of water replenishment. The outflow is a measure of demand, i.e., the rate of water withdrawal or consumption. The stock of water reflected by the level of water in the lake will fall if inflow < outflow, rise if inflow > outflow, and remain steady if inflow = outflow. Water use is sustainable if the rate of withdrawal is ≤ rate of replenishment. When inflow equals outflow the rate of input equals the rate of output, and we have a steady-state in which the water stock remains constant. Steady-state systems are stable because they don't change with time. We can model dynamic systems such as our hypothetical lake by using stocks and flows, a topic we will explore in detail in Chapter Two. Modeling allows us to evaluate future scenarios in which changes in the environment or in human resource use affect the supply of renewable resources such as water over time. For example, if the inflow rate decreases during a drought, we can model the rate of water depletion and estimate when the lake will go dry.

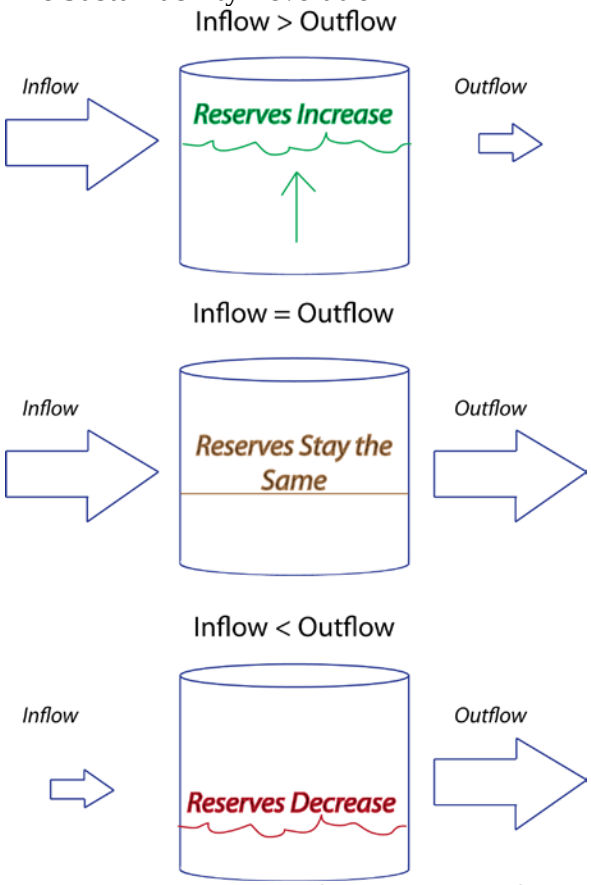


Figure 5. Illustration of the concept of steady state. Arrow size is proportional to the flow rate (flux). In a steady state the amount of water in the reservoir does not change because inflow equals outflow.

For critical renewable resources such as water, it is wise to establish a safety margin by maintaining a demand (rate of withdrawal) that is less than the average rate of replenishment. For example, during a drought the rate of replenishment drops. To maintain sustainability, the demand must decrease at the same rate as supply. During droughts communities usually accomplish this through water conservation efforts or by temporarily drawing on nonrenewable supplies such as deep groundwater. This example also illustrates that we can temporarily use a renewable resource such as lake water faster than it is replenished. When we do, the lake water level drops. If we continue to withdraw water faster than it is replenished, the lake will eventually dry up.

Food serves as another example. We can estimate the maximum number of people that can be fed in a specific community, given the limitations of fertile land area, annual precipitation, etc.. Yet what if a drought or flood wipes out half the crop? To increase resilience, the community could limit population to half the maximum number that they could feed in a good year. In good years the community could store the surplus food to use in lean years. When the community has the maximum number of people that can be fed in a good year, it operates at the physical limit of the food system because it cannot afford to save a surplus for lean years. During a lean year the food supply system cannot keep pace with demand. The overshoot of the system is the amount that demand exceeds supply. As the degree of overshoot (the gap between supply and demand) increases, the risk of starvation increases. Thus, we can increase food security by using the food supply system sustainably, i.e., by maintaining a demand on renewable systems that is less than the maximum rate of replenishment. Economic sustainability works the same way: if you save economic capital (money) at a greater rate than you spend it, supply is greater than demand, and you accumulate a surplus in your bank account. However, if you spend money faster than you earn it, you are in overshoot, and you will eventually deplete your stock of money.

To recap, sustainability is a process in which society preserves and grows social, economic, and environmental capital by ensuring that the supply of each form of capital is greater than demand. This increases security and ensures that future generations will be able to meet their needs.

Renewable and Nonrenewable Resources and the Laws of Sustainability

A main message of this book is that our society will experience resource shortages in the near future because we have been using these resources unsustainably, either because they are nonrenewable or because we used renewable resources faster than they could be replenished. Some resources will become scarce within the lifetimes of the baby-boomer generation. Others will become scarce during the lifetimes of their children. To understand this problem, we must introduce some terms and concepts. Natural processes can replace renewable resources. They can't, however, replace non-renewable resources, or they do so at such a low rate that we essentially have a fixed supply of them. Non-renewable resources are fixed in quantity, so the faster we use them, the faster they disappear. Fossil fuels fall into this category because it takes millions of years for nature to produce oil and coal from plants.

Overall, we are at greater risk of running out of non-renewable resources. However, we can also run out of renewable resources if we use them faster than they can be replaced. For example, marine fisheries are collapsing worldwide because overfishing has decimated populations of certain fish species to critically low levels or even forced them to extinction. If left alone to breed, they may regenerate their populations to preexisting levels - but that could take many decades. You may have noticed that certain species of fish such as cod have essentially disappeared from grocery shelves; this is because the commercial catch of cod has declined rapidly in recent years, to the point where in the year 2000 the World Wide Fund for Nature added cod to its list of endangered species, stating that the worldwide cod catch had decreased 70% in the preceding 30 years due to decreasing cod abundance, and that cod were at risk of becoming extinct within 15 years[ix]. Thus, the cod-fishing industry is unsustainable, and environmentally-minded consumers should avoid eating cod.

A renewable resource stock can grow or shrink, depending on the relative rates of replenishment (inflow) and extraction (outflow) (Figure 5). For our cod example inflow < outflow, meaning that the rate of extraction exceeds the rate of replenishment. Resources that fall in this category are the ones we must be concerned about, and we will examine many examples, particularly water. The sustainable approach to managing renewable resources is to harvest the resource at the same rate it is produced, maintaining a steady state. Sustainable use of renewable resources is desirable because it guarantees long-term availability of those resources.

We can see from these examples that renewable resources are flow or rate limited, while nonrenewable resources are stock limited (Gleick and Palaniappan 2010). We essentially have an infinite supply of renewable resources such as water and solar energy because they are constantly replenished, but the rate at which we use them is limited by the flow rate.

These concepts are summarized in The Laws of Sustainability. According to Ecological Economist Herman Daly, the sustainable rate of use can be no greater than...

- the rate of regeneration of a **renewable resource.**
- the rate at which a renewable resource, used sustainably, can be substituted for a **nonrenewable resource**.
- the rate at which a **pollutant** can recycled, absorbed, or rendered harmless in its sink.

"Any activity that causes a renewable resource stock to fall, or a pollution sink to rise, or a nonrenewable resource stock to fall without a renewable replacement in sight, cannot be sustained (Meadows, Randers et al. 2004)."

Robert Bolman[x] expanded on Daly's Laws of Sustainability, postulating the following five conditions for sustainability:

1. Renewable resources shall not be used faster than they can regenerate.
2. Nonrenewable resources shall not be used faster than renewable substitutes (used sustainably) can be developed.
3. Pollution and waste shall not be put into the environment faster than the environment can recycle them or render them harmless.
4. The human population and the physical capital plant must be kept at levels low enough to allow conditions 1, 2 and 3 to be met.
5. The previous four conditions must be met through processes that are democratic and equitable enough that people will stand for them.

Now that we have introduced the concepts of weak and strong sustainability and the Laws of Sustainability, we can understand the more sophisticated definition of sustainability given by the Global Footprint Network (GFN 2009): "The essence of sustainability is a commitment to human well-being – well-being that lasts. We believe that maintaining "sufficient amounts of all the assets that matter for wellbeing" in order to make well-being last necessitates the following: either a) using the key ingredient to every value chain – living natural capital – no faster than it regenerates ("strong sustainability"), or b) if these assets are used faster, that these assets are not depleted faster than other human-made processes are able to compensate for the lost services from the living natural capital ("weak sustainability").

Naturalists versus Exemptionalists

Till now man has been up against Nature; from now on he will be up against his own nature. ~Dennis Gabor, Inventing the Future, 1964

There is a basic antagonism between the philosophy of the industrial age and the philosophy of the conservationist. – Aldo Leopold, in "A Sand County Almanac"

To live sustainably, people need to learn how to work with, rather than against, nature. Environmental problems develop when an unhealthy relationship exists between humans and the environment. The ways people approach, treat, and think of nature depend on their self-image. According to Harvard biologist Edward O. Wilson (1998) there are two competing types of human self-image: exemptionalist and naturalist, also termed anthropocentric and ecocentric respectively (Vallero and Brasier 2008). In theory there is a continuous range of ethical viewpoints between these two extremes, but most people are either one or the other.

Exemptionalists are anthropocentric, and believe that humans exist apart from environment and hold dominion over it. In western civilization, many believe that God made the environment for our benefit and that we have the freedom to use it as we see fit. Exemptionalists assert that we can use technology to improve our current environment or adapt to any new environments. In contrast, naturalists believe that humans have perfectly adapted to our environment through millions of years of evolution, but that we are now rapidly destroying that environment. Our genes prescribe that we can be happy only when we live in our original, natural environment. Habitat selection, a basic principle of organic evolution, states that species prefer and gravitate to the environment in which their genes were assembled. Thus, we are completely dependent on our environment, including other species, and we must take steps to preserve the ecosystems that support us[xi].

Exemptionalists argue that technology can provide a substitute for nature. However, scientists and engineers have tried to build a closed, self-supporting system and failed miserably. Biosphere 2 taught us that we cannot engineer sustainable life support systems for human communities; only earth and its ecosystems can keep us alive. Biosphere 2 is a 3-acre structure built in Oracle, AZ between 1987 and 1991. Scientists designed it to be a sustainable, self-contained ecosystem that could support human life. The overall cost of the project has been $200 million through 2007. The 1991-3 experiment was aborted due to wildly fluctuating levels of O_2 and CO_2 in the artificial atmosphere, personality conflicts arising from poor management, and planners not accounting for the effects of a closed environment. So currently our species cannot maintain a closed, self-supporting ecosystem, and we still require the natural environment to survive.

Wilson supports the Naturalist view. He believes our environment is fragile and that with our current technology we cannot create artificial sustainable environments. Exemptionalists claim that new technologies (power of the human mind) and free-market economies will provide adequate resources for the growing population; however, Wilson points out that there are limits to the amounts of water, arable land, oil, and food (including seafood) that can support us, and that global warming may reduce those limits. Exemptionalists are taking a gamble when they advise pressing forward with current policies and assume that technology will provide solutions to these growing problems before they become disasters. Ecologists like Wilson don't like these gambles because they know that if we lose, we lose everything.

Wilson (1998) also believes that economists, who generally take the exemptionalist point of view, promote policies that are inconsistent with sustainability. Their economic models ignore human behavior and the environment. They assume that all countries have adequate resources and can achieve the same standard of living as the U.S.. However, the U.S. can only maintain its standard of living by using the resources of other countries ("economic miracles are not endogenous"), which we will discuss in detail later. Furthermore, economists do not use full-cost accounting; i.e., they use only economic capital and not social or environmental capital in their models.

Overall, exemptionalists try to conquer nature rather than put it to good use. They favor the "hard approach" and attempt to control natural processes. They straighten rivers and dam them up, but nature always fights back: dams fail or the reservoirs behind them fill with sediment and require constant dredging; seawalls erode and collapse under the constant assault of waves; rivers prefer to meander, so they tend to break out of straight, engineered channels through erosion.

Naturalists prefer to work with, rather than against, nature. They give a river "room" to meander and reduce the risk of flood damage by limiting development to outside the river's floodplain. They plant or preserve trees along the riverbanks to slow the rate of erosion and provide shade for aquatic species. Nature is a powerful force; it is constantly at work, and while our short bursts of work may be more intense, and the use of energy from oil can magnify our efforts, eventually Nature will win because it has limitless time. How did streams cut through mountains to create water gaps? How did ancient mountains almost completely erode away? In "The World Without Us", Alan Weisman (2007) describes what would happen to our cities, buildings, and infrastructure if humans disappeared. Nature would quickly and completely erase the evidence of our existence. Nature can persist without humans, but humans cannot exist without nature. The scientific evidence strongly supports the naturalist view: humanity and nature are interconnected, and humanity is intensely dependent on natural systems for life support.

Ultimately we develop our relationship with nature from our own experiences and by learning from our parents. Sadly, many people have never truly experienced nature, and the proportion of Americans who fall in this category is increasing. An increasing proportion of Americans view nature as "icky" and unnecessary. Usually these people had parents with similar views, and as a result those parents never introduced their children to nature by camping, fishing, or hiking with them. Isolation from nature inhibits the development of an appreciation of its beauty, and its necessity.

When I was about 12 years old, my parents took their eight children to the Algonquin Provincial Park in the Ontario province of Canada. What an inspired vacation choice! My brothers still talk about that trip, and two of them recently returned with their families. It was as close to true wilderness as any of us had seen, and I've always appreciated how brave my parents were to take eight children there. At night we could hear wolves howling. Bears would pass through our campsite every evening. The fishing was incredible. Even the "icky" parts of nature like leeches made lasting memories for us young boys. That trip taught us an appreciation of nature that we all still have. In July 2010 I returned to Algonquin for a four-day canoe trip with two of my brothers and our sons. The park was still beautiful, but even after canoeing to lakes lacking people we saw very little wildlife, caught only one small fish, and never heard any wolves. Have humans affected the park to that degree in merely 35 years?

Fortunately you don't have to go far from civilization to experience nature in its most elemental form. As an adult I was fortunate to visit Muir Woods National Monument just outside San Francisco, CA. The 200-foot redwoods in this primitive coastal forest are awe-inspiring (further north they get up to 379 feet tall). With the fog and mist they made the place feel raw, and ancient. As John Muir said, "*This is the best tree-lovers monument that could possibly be found in all the forests of the world.*[xii]" Experiences like this are important because they give us perspective, and help us develop a sense of place in the universe.

The best advice I can give to parents is to take their children camping. In my experience it is always a bonding experience, and it teaches children the value of nature. Children learn so much from being outside; in my experience, time spent in nature always provides more educational value than the same amount of time spent in the classroom. As Albert Einstein said, "Look! Look! Look deep into nature and you will understand everything." Every child should have the opportunity to experience the wilderness, or something close to it. I personally don't know anyone who experienced nature this way and doesn't value and want to protect it.

Many people fear nature, and that fear is not irrational. Nature can be a dangerous place, especially for those who have no experience living "uncivilized." Since I am an experimentalist, I have little field experience compared with most geologists. However, the little time I've spent in the field was filled with hazards. I've spent no more than one week camping and off-roading in the desert south of Las Vegas, Nevada, but during that time I faced several life-threatening situations. About five miles from the nearest road, my rented Jeep Cherokee stalled with the temperature at 104°F. It was so hot that the soles of my boots fell off; presumably, the glue melted. I momentarily panicked because I knew we didn't have enough water to make it very far, but fortunately the car restarted. On that same trip, a large rattlesnake reared up just a few feet in front of me. On another trip I off-roaded and then left the SUV for a hike. It started to snow so heavily that I couldn't see the SUV. Fortunately I had used a GPS to mark the location of the SUV, so I easily found it. One time after camping in Nevada we continued on to the White Mountains of eastern California with some experienced field

geologists. We camped at an elevation of roughly 10,000 feet, where the oldest trees in the world, bristlecone pines, are located. Again I recorded the location of our base camp on my GPS. We spent an entire day hiking through the rocky terrain, using a topographic map to guide us. During the hike we found evidence of a mountain lion. As evening fell it started to get very cold as we started back for camp. I began to worry that we were lost because the GPS indicated that we were moving away from camp. Eventually I persuaded the rest of the group to change direction, and we used the GPS to guide us back to camp. We were fortunate to find camp because it got down to 10°F that night. It turned out that my student had incorrectly marked the location of the base camp on the topographic map, so we had essentially been lost the entire day. The point is that even people with significant outdoors experience can get lost or have bad luck (vehicle breaks down), and quickly get into real trouble when out in the wilderness. Sudden storms can spring up, deadly animals can attack, and poisonous plants, insects, and animals can kill. In certain places in the world like Australia, the poisonous animals almost outnumber the nonpoisonous.

Most of us are aware of the dangers nature presents and recognize how hard it would be to live without our creature comforts. If our society can successfully transition to sustainable living, we will not be forced to 'live off the land' and face the dangers of nature first-hand. We won't have to abandon the security of our homes and hunt in the wilderness for food. Adopting a sustainable lifestyle will increase your security by making you more self-reliant, and society becoming sustainable will reduce the chance of economic collapse and loss of a basic infrastructure and services. If you learn how to grow your own food, you will not be forced to starve or become a hunter-gatherer if the grocery stores run out of food. However, we can only become sustainable if we preserve environmental capital such as soil and water and give nature the respect it deserves, and this requires abandoning the exemptionalist mindset. To grow your own food, you must preserve your soil and a source of fresh water, but you must also have knowledge and skill. Read on.

The Value of Ecosystem Services and Cost of Environmental Degradation

A healthy environment is vital to humanity. Our well-being and even our existence is dependent upon reliable ecosystems (Figure 6). The natural environment offers invaluable services and resources such as waste absorption, fresh water, clean air, soil for growing food, plants and trees that provide oxygen and shade, and animals that support human populations via processes such as pollination and the conversion of waste back to soil. Yet most people take these benefits, these "ecosystem services" that nature provides, for granted. Some even view nature, and the regulations put in place to protect it, as obstacles to development. "In our current way of seeing the world, the environment is just a collection of problems; we won't protect it until we correctly see nature as a collection of solutions - a regenerating form of wealth we literally can't live without...Why not use knowledge about how nature works, to meet more of our needs ((Wann 2007), p. 108)?" Changing our lifestyles in order to preserve ecosystems and the services they provide is key to achieving sustainability.

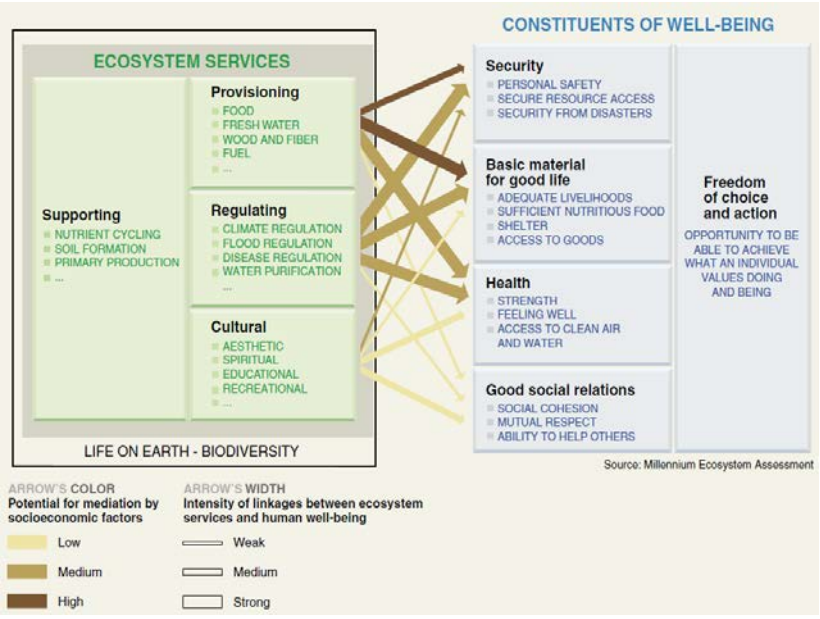


Figure 6. This Figure depicts the strength of linkages between categories of ecosystem services and components of human well-being that are commonly encountered, and includes indications of the extent to which it is possible for socioeconomic factors to mediate the linkage. (For example, if it is possible to purchase a substitute for a degraded ecosystem service, then there is a high potential for mediation.) In addition to the influence of ecosystem services on human well-being depicted here, other factors—including other environmental factors as well as economic, social, technological, and cultural factors—influence human well-being, and ecosystems are in turn affected by changes in human well-being. From the Millennium Ecosystem Assessment, 2005.

In the field of ecological economics, ecosystems are considered capital assets because they provide services such as clean water. Many examples illustrate that taking the soft path and relying on nature to provide ecosystem services is cost effective and preserves the beauty of nature. Table 1.5 lists some of the ecosystem services provided by nature. According to the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005), a four-year research effort by 1,360 of the world's leading scientists commissioned to measure the actual value of natural resources to humans and the world, nature provides roughly $33 trillion worth of ecosystem services each year. The Assessment notes that "Ecosystem services, particularly food production, timber and fisheries, are important for employment and economic activity. Intensive use of ecosystems often produces the greatest short-term advantage, but excessive and unsustainable use can lead to losses in the long term. A country could cut its forests and deplete its fisheries, and this would show only as a positive gain to GDP, despite the loss of capital assets. If the full economic value of ecosystems were taken into account in decision-making, their degradation could be significantly slowed down or even reversed."

Table 1.5: Ecosystem Services Provided by Biota*

- Purification of air and water.
- Water absorption and storage; mitigation of drought and floods.
- Decomposition, detoxification, and sequestering of wastes.
- Regeneration of soil nutrients.
- Pollination, pest control, seed and nutrient dispersal.
- Moderation of wind and temperature extremes.
- Provision of a wide variety of agricultural, medicinal, and industrial products.
- Evolution and maintenance of the biotic gene pool and the biodiversity that performs all of the above tasks.
- Lessons in survival, resilience, evolution, and diversification strategies that have proved themselves over three billion years.
- Unparalleled aesthetic, spiritual, and intellectual uplift.
- The value of ecosystem services is valued in trillions of dollars per year.

* (Meadows, Randers et al. 2004):

Humans are an integral part of ecosystems. Because human population is increasing at an exponential rate, our impact on the environment is increasing at an exponential rate (more on this in Chapter 2). "The structure of the world's ecosystems changed more rapidly in the second half of the twentieth century than at any time in recorded human history, and virtually all of Earth's ecosystems have now been significantly transformed through human actions (Millennium Ecosystem Assessment 2005)."

Environmental degradation results in the loss of ecosystem services. Most people agree that "the quality of the environment is important both to their own wellbeing and to the common good (Adams 2006)." Many societies in the past collapsed because of environmental degradation and loss of ecosystem services (see Chapter 2 and (Diamond 2005)).

Degradation of ecosystem services disproportionately harms poor people. Modern Haiti, discussed in Chapter 2, is an excellent example. As a result, the UN made Millennium Development Goal #7 “Ensure Environmental Sustainability,” with the following objectives[xiii]:

Target 7.A: Integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources

Target 7.B: Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss

7.1 Proportion of land area covered by forest

7.2 CO2 emissions, total, per capita and per $1 GDP (PPP)

7.3 Consumption of ozone-depleting substances
7.4 Proportion of fish stocks within safe biological limits
7.5 Proportion of total water resources used
7.6 Proportion of terrestrial and marine areas protected
7.7 Proportion of species threatened with extinction

Target 7.C: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation

7.8 Proportion of population using an improved drinking water source
7.9 Proportion of population using an improved sanitation facility

Target 7.D: By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers

7.10 Proportion of urban population living in slums

Much of the environmental damage incurred by humans is unexpected. Due to the complex interdependencies in ecosystems, any human-driven environmental changes will likely have unintended consequences, as argued by Chris Bright in his article "Anticipating Environmental Surprise" (Bright 2000). For example, in southern Honduras, the removal of soil-anchoring vegetation for agricultural purposes diminished soil absorbency and resulted in both desertification (a negative effect) and the reduction of malaria-bearing mosquito populations (which initially seemed like a positive effect). Over time, the land became uncultivable. When Hurricane Mitch struck in 1998, much of the soil was washed away in mudslides that displaced half the population and reduced agricultural production by 95 percent. Meanwhile, communities in the area developed a lower immunity to malaria. When the low-immunity population moved north to rainforests that could support them, they encountered high concentrations of malaria-bearing mosquitoes, which lead to a rapid rise in the number of malaria cases. This chain of unpredictable events illustrates the complexity of our environment and its sensitivity to human-driven change. To reduce the potential for negative "environmental surprises," we should practice the *precautionary principle* and minimize how much change we introduce to the environment.

As an example of ecosystem services and the effects of environmental degradation we will look at forest ecosystems and the problem of deforestation. Later we will cover most of the ecosystem services listed in Table 1.5.

Forest Ecosystems and Deforestation

Forests have a high density of trees and host a high diversity of wildlife. Primeval forests covered most of Europe and North America ten thousand years ago, but now only small pockets of primary (old-growth) forests exist. Globally forests cover 30% of land area, compared to pre-human coverage of ~50%. The importance of forests led the United Nations to declare 2011 the International Year of Forests.

Forests provide a host of ecosystem services. They host roughly 80% of the earth's species, and produce abundant organic matter that accumulates to form thick, rich soils, especially in temperate regions. They play an essential role in the global cycling of nutrients such as carbon and nitrogen (Raven, Berg et al. 1995). Forests act as both sources and sinks. For example, forest trees are a sink for atmospheric carbon dioxide, which they fix through the process of photosynthesis:

$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6O_2$

This chemical reaction shows that trees are also a source for atmospheric oxygen. In fact, trees are the primary source of the oxygen we breathe. Forest trees effectively provide shade and store water, keeping an area cool and humid even during hot, dry spells. Forests therefore exert a strong control on local climate. Finally, forests provide wood, which has many unique qualities that make it a versatile and irreplaceable resource used for fuel, in construction, and in the arts. The timber industry is an important part of the global economy, accounting for roughly 1% of world gross domestic product (GDP), about U.S. $200 billion annually[xiv]. Roughly 1.6 billion people depend on forests for their livelihoods, and about 300 million people live in forests[xv].

Wood is a valuable and renewable resource. However, trees are treated as a nonrenewable resource in most parts of the world, and they are being harvested at an unsustainable rate. Deforestation is a decrease in the stock of wood, a renewable resource, that results from harvesting timber faster than it regrows, an

unsustainable practice (Meadows, Randers et al. 2004). Unfortunately, because trees grow slowly, it is easy to harvest them faster than they replenish.

The consequences of deforestation include loss of timber & other forest building materials, soil erosion, loss of soil fertility, sediment loads in rivers, loss of watershed protection and hence of potential hydroelectric power, and decreased rainfall (Diamond, 2005). Deforestation is the leading cause of desertification globally, and it is also a leading cause of global warming. Particularly troublesome is slash and burn farming, where trees are simply chopped down and burned, a complete waste of a valuable resource. Trees store CO_2, as shown by the photosynthesis reaction. Deforestation eliminates this sink for atmospheric CO_2, and burning the wood also releases the CO_2 stored in the tree, making slash and burn farming a double whammy for climate change. Most deforestation today occurs in tropical forests, and current harvesting rates could result in unprotected tropical forests disappearing as early as 2054 (Meadows, Randers et al. 2004).

So how can we make forest use sustainable? First and foremost we have to decrease the amount of wood we consume by reducing paper use, recycling paper, and increasing the efficiency of wood-burning stoves and lumber and paper mills (Meadows, Randers et al. 2004). We must pressure politicians to change policies by eliminating logging subsidies. Finally, we can help grow the sustainable forestry industry by choosing lumber certified with the stamp of the Forest Stewardship Council (FSC).

The harvesting of hardwood presents an excellent example of how society adapts to a resource shortage. In the early years of the U.S., hardwood was abundant. However, as the nation expanded and population grew, Americans began to harvest hardwoods unsustainably. Today almost no old-growth forest remains in the U.S., and the price for hardwood has skyrocketed. Hardwood furniture was becoming expensive when my grandparents bought their furniture; those pieces of furniture are now valuable heirlooms in my family. My parents had a mix of inherited hardwood furniture and newer, less expensive furniture that substituted cheaper materials for hardwood. Today even expensive furniture is often made from wood laminates or from softwoods like pine rather than solid hardwoods; cheap furniture is made from pressed particle board, which is made of small pieces of wood and sawdust bonded together by VOC-based adhesives. As a society we have accepted this change. But will we always be able to find substitutes when we run short of natural resources?

Measures of Environmental Degradation

To measure our progress towards sustainability we need quantitative measures. Environmental degradation is a loss of environmental capital, so we need a measure of environmental capital. Perhaps the most useful measure in use today is the Ecosystem Wellbeing Index (EWI), which is an average of indices of Land (L), Water (W), Air (A), Species and genes (S), and Resource Use (R). A country has a high EWI if ((Prescott-Allen 2001), p. 60):

Table 1.5: A High Ecosystem Wellbeing Index Means...

Land diversity	All major land ecosystems are maintained or restored in large units with minimal loss of the habitats and communities within them.
Land quality	Soil degradation on cultivated and modified lands is kept close to degradation rates on natural lands.
Inland waters	All major aquatic ecosystems, both inland and
Sea	marine, are maintained or restored in large units with minimal loss of the communities and habitats within them and minimal stress from pollution and water uses.
Global atmosphere	Pollutants that disrupt the chemical balance of the global atmosphere are eliminated or substantially reduced.
Local air quality	Local air pollutants are below levels that affect people or the ecosystem.
Wild diversity	All native wild species are maintained, and extinctions are reduced to background rates.
Domesticated diversity	As much as possible of the heritage of crop varieties and livestock breeds is maintained.
Energy and materials	Consumption of energy and materials and

Resource sectors	extraction and production of resources are within the carrying capacity of the ecosystem.

(Figure 7) (after (Prescott-Allen 2001)) shows the composite HWI and EWI scores for the U.S. and a sample of other countries for comparison. Note that the U.S. plots in the "almost unsustainable" field because its ecosystem wellbeing index (EWI) is low. No countries plot in the "sustainable" or "almost sustainable" fields. Sweden is the closest to being sustainable, plotting squarely in the "medium" field, while Canada, Norway, Costa Rica, and Russia also plot in the medium field. Clearly our society has a long way to go before we achieve sustainability.

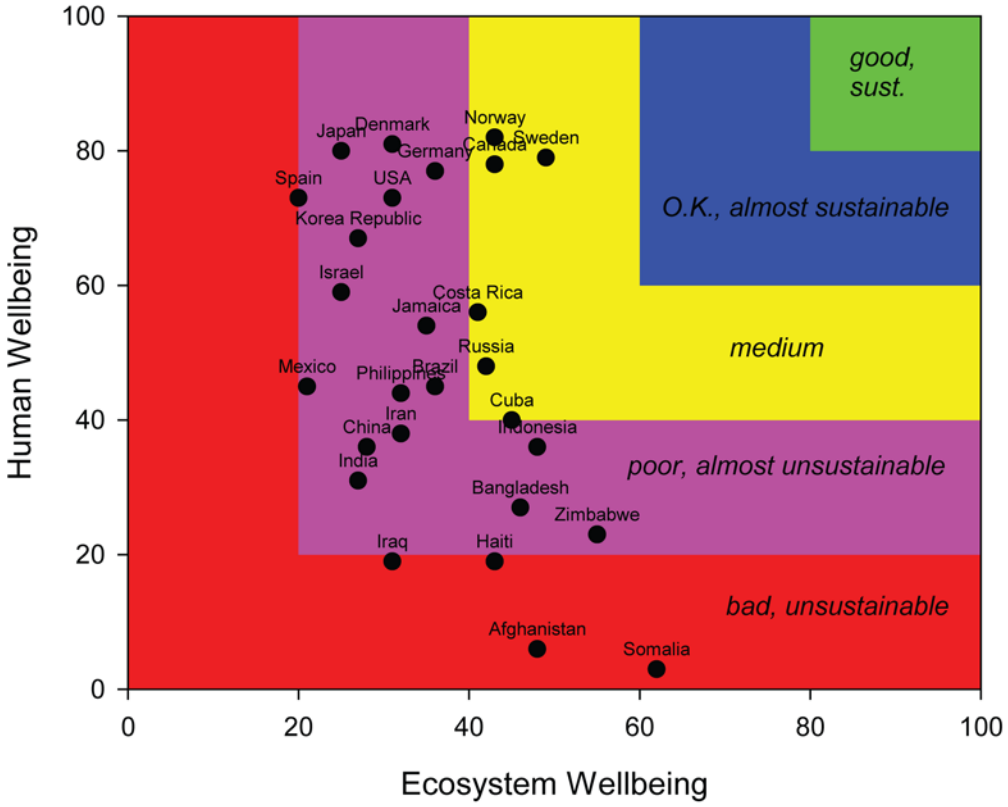


Figure 7. IUCN sustainability diagram. Data from Prescott-Allen (2001).

Biocapacity and the Ecological Footprint

Nature cannot be fooled. - Richard Feynman, American physicist

The economic and technological triumphs of the past few years have not solved as many problems as we thought they would, and, in fact, have brought us new problems we did not foresee. - Henry Ford II

Sustainability is a balance between supply and demand of social, economic, and environmental capital. As a global society, our current lifestyle is clearly unsustainable. The Earth's population will increase from six to nine billion by 2050, yet we are already pushing the limits of our resources. Humans use over half the accessible water and about 40% of the energy from the sun captured by plants through photosynthesis. We have created a large hole in the ozone layer and increased the concentration of carbon dioxide in the atmosphere by more than a third in the last 175 years. The rate of species extinctions is growing exponentially; we are in the midst of earth's sixth mass extinction event, one primarily caused by humans. We have fully exploited nearly 80 percent of our fisheries. Clearly, we cannot afford to double human population from six to twelve billion.

Many people think that the earth has a limitless capacity to meet our resource needs and absorb the waste that we produce. However, the global population – and particularly the U.S. population - is currently in

ecological overshoot: we have exceeded the earth's capacity to provide resources and absorb our waste. There is "a finite amount of land on the planet - 28 billion acres of biologically productive land and sea. Dividing that finite acreage by 6.5 billion humans, each of us has a theoretical right to about 4.3 acres ((Wann 2007), p. 23)." This brings us to the concept of the ecological footprint (EF), the amount of land required to provide the resources used, and absorb the waste produced, by an individual or organization. The EF measures how much of earth's resources each person consumes and how much of an impact each individual has on the environment. The EF represents the human burden on the environment, the total impact of humanity on nature. It is the "sum of all effects of resource extraction, pollution emission, energy use, biodiversity destruction, urbanization, and the other consequences of physical growth (Meadows, Randers et al. 2004)." EF calculations vary; most attempt to estimate the area of earth and sea required to support an individual's lifestyle by regenerating renewable resources and absorbing wastes. If measured in productive land area, the global ecological footprint is 6.8 acres per capita – higher than the 4.3 acres available for each person. Thus, the global population is currently in ecological overshoot: we have exceeded the capacity of the earth to provide resources and absorb our waste. The U.S. ecological footprint far surpasses the global average at 23.5 acres (Hails 2008). The EF is a useful measure of sustainability because it has meaningful units, unlike other measures of sustainability (Stiglitz, Sen et al. 2009). It has units of area because it is calculated by summing the land areas required to provide each of the ecological services required to maintain our current quality of life.

I used the Ecological Footprint Quiz by Redefining Progress[xvi] and found that my ecological footprint is 145 acres. If everyone on earth required the same amount of land, we would need 3.7 earths. According to the EF Quiz, the U.S. average ecological footprint is 246 acres, or 6.4 earths. (These numbers disagree with those mentioned in the previous paragraph because different EF calculators do the calculation in different ways. The Redefining Progress number of acres may be larger because it considers all available land and sea, whereas the numbers in the previous paragraph only considered biologically productive land and sea. Therefore, use only one calculator when making footprint comparisons.) My current EF reflects the fact that our family of four lives in a large house that requires large amounts of energy. After our children finish grade school, we plan to move into a smaller house or condominium closer to our jobs and to the heart of the city, and that will greatly reduce our footprint.

Here is how I currently am living in an effort to reduce my EF. I only drive to work ~2 times per week, telecommuting on other days. In the morning my wife and I make organic, shade-grown, fair trade coffee using unbleached filters; we drink it will checking email on our energy star-rated notebook computers. We then exercise 45-60 minutes using a DVD routine. On sunny days I make dinner by collecting ingredients from our gardens and adding them and store-bought organic ingredients to a HotPot and place it outside for solar cooking. On sunny days I also do laundry so I can line-dry my wet clothes.

Biocapacity refers to the maximum amount of ecological services and resources that Earth can provide. It is a measure of supply (S), expressed as the amount of productive land available for production per capita. Our use of ecosystem services and resources is sustainable when we demand less than the Earth can supply, i.e., when the global ecological footprint is less than the global biocapacity. The global average biocapacity in 2005 was 5.2 acres per person (note that over time biocapacity decreases as population increases and the amount of arable land decreases – see (Figure 8) from Leape and Humphrey (2010)). The ecological overshoot O = S-D is the best measure of sustainability; it expresses the difference between inflows (S, supply) and outflows (D, demand); we can maintain a steady state when the two are equal. The difference between the global biocapacity (S) and global ecological footprint (demand D) is currently -1.5 global acres per capita, with the negative sign again indicating that demand is greater than supply and that we have a global ecological overshoot (Figure 9). For the U.S. the overshoot is -10.9 acres per capita (Hails 2008), which partly explains why the U.S. has to import so many goods. Unfortunately, the footprint now exceeds the biocapacity, and the gap between the two is increasing. In the unsustainable situation where demand is greater than supply, as it is now, we build up an ecological debt. (Figure 10) adapted from (Hails 2008) illustrates an optimistic scenario in which we act quickly to close the gap between supply and demand. The global biocapacity (supply) is one planet earth. The global EF (demand) increases to ~1.3 planet earths in 2005, after which increasing use of sustainable practices decreases the global EF until it becomes one earth in the year 2045 and the overshoot (= biocapacity – EF) becomes zero. Until the year 2045 persistent ecological overshoot resulted in accumulation of ecological debt (equal to the area under the EF curve and above the biocapacity curve for all years that EF > biocapacity, labeled "Ecological debt"). Continuing decline of the global EF results in the buildup of

"biocapacity reserve" (green area) that offsets the accumulated ecological debt. We can build up reserves[xvii] only if we decrease demand until it is less than supply.

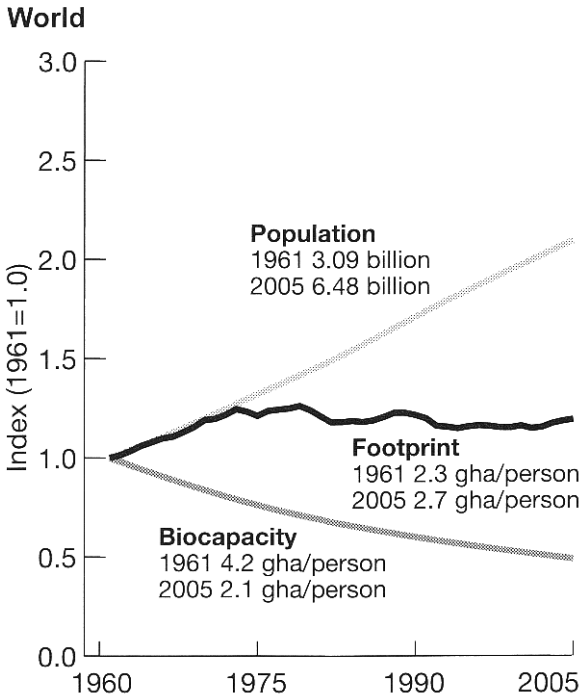


Figure 8. Sustainability trends over time. From Leape and Humphrey (2010).

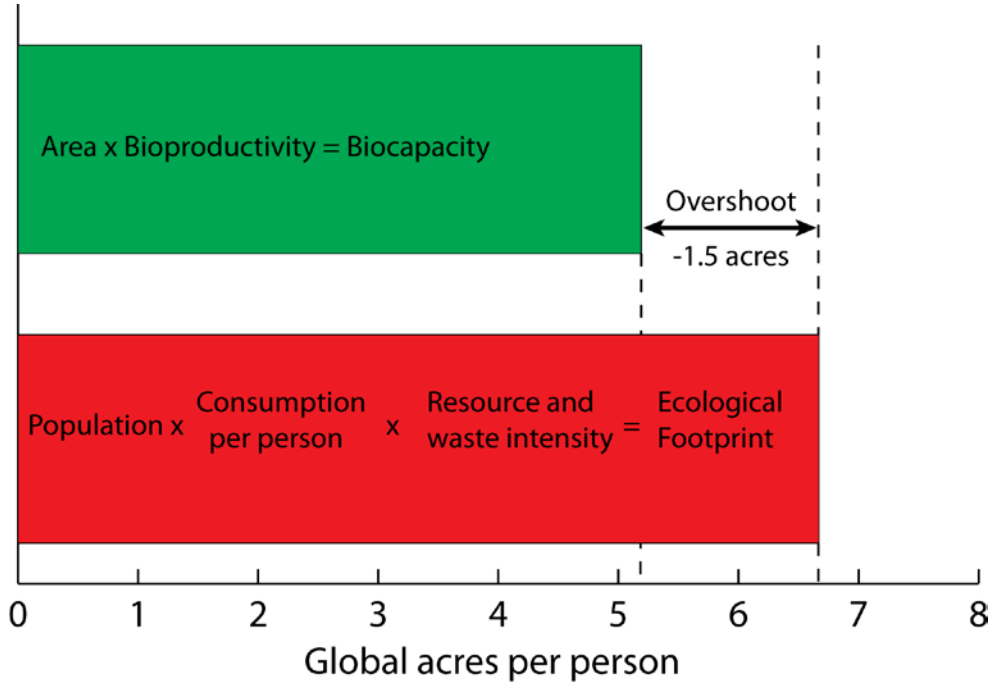


Figure 9. Global biocapacity and ecological footprint values in acres in the year 2008. Sustainability requires that the ecological footprint be reduced until it is equal to or less than the biocapacity, so that ecological overshoot is eliminated. Adapted from Hails (2008).

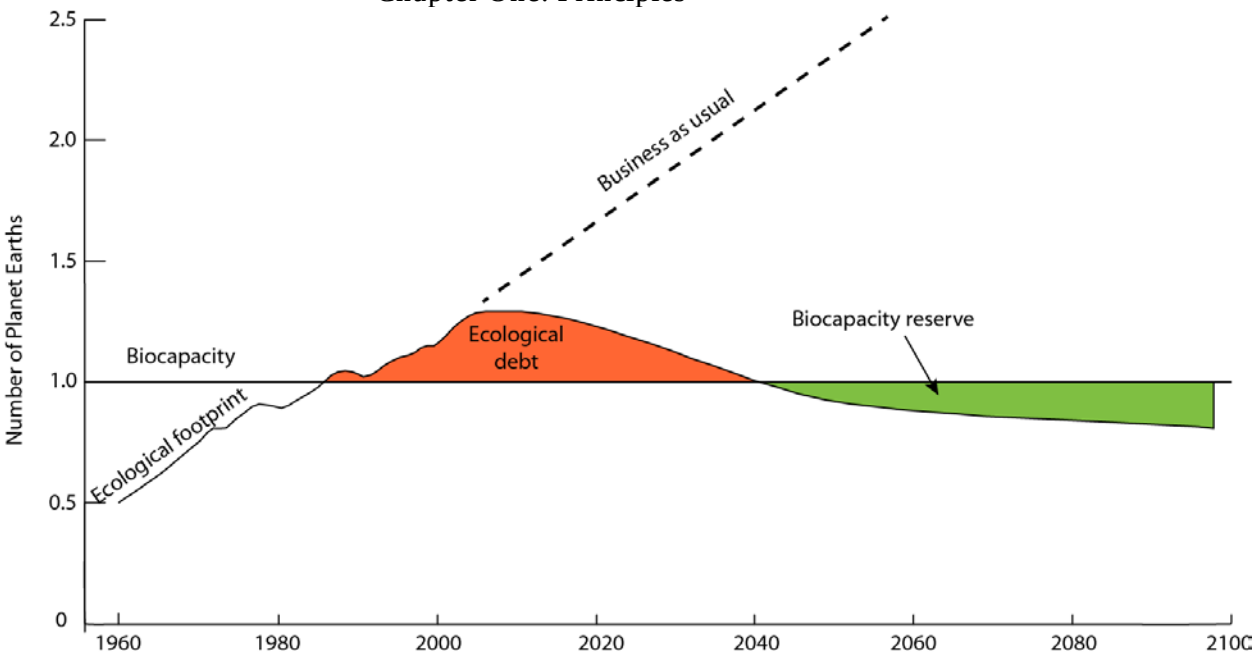


Figure 10. Schematic illustration showing changes in the global ecological footprint relative to global biocapacity over time. Adoption of sustainable practices end ecological overshoot by the year ~2050; Further decreases in EF allow accumulation of biocapacity reserve, which eventually offsets accumulated ecological debt. Adapted from Hails et al. (2008).

Remember that the EF represents the land area required to maintain the current quality of life. However, it is hard to remember land areas in acres, so the EF is often divided by the biocapacity in acres to obtain a unitless number. When this is done using the global average biocapacity, the resulting EF is expressed as the number of earths required to maintain the current standard of living.

To recap, sustainability preserves and grows economic, social, and environmental capital so that current and future generations can meet their needs and maintain a high level of well-being. It can also prepare us for the coming challenges posed by Peak Oil and Global Climate Change.

References

Adams, W. M. (2006). The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. International Union for Conservation of Nature: Report of the IUCN Renowned Thinkers Meeting**:** 18.

Bright, C. (2000). Anticipating Environmental Surprise. State of the World 2000: A Worldwatch Institute Report on Progress Toward a Sustainable Society. L. R. B. e. al., W. W. Norton**:** 368.

Diamond, J. (2005). Collapse: How Societies Choose to Fail or Succeed. New York, NY, Viking Penguin.

Dodds, S. H. (2008). "DEFINITION OF SUSTAINABILITY--2." Ecos (141): 15(11). http://find.galegroup.com/gtx/infomark.do?&contentSet=IAC-Documents&type=retrieve&tabID=T003&prodId=ITOF&docId=A179659810&source=gale&srcprod=ITOF&userGroupName=tel_a_vanderbilt&version=1.0.

Dresner, S. (2008). The Principles of Sustainability. London, UK, Earthscan.

Ehrenfeld, J. (2008). Sustainability by design : a subversive strategy for transforming our consumer culture. New Haven, New Haven : Yale University Press.

GFN (2009). Global Footprint Network response to The “Commission on the Measurement of Economic Performance and Social Progress” (“Stiglitz Commission”) Report.

Gleick, P. H. and M. Palaniappan (2010). "Peak water limits to freshwater withdrawal and use." Proceedings of the National Academy of Sciences **107**(25): 11155-11162. http://www.pnas.org/content/107/25/11155.abstract.

Gore, A. (2009). Our Choice: A Plan to Solve the Climate Crisis, Rodale, Inc.

Hails, C., Ed. (2008). Living Planet Report, World Wildlife Federation, Zoological Society of London, and the Global Footprint Network.

Leape, J. P. and S. Humphrey (2010). Towards a sustainable future. Global Sustainability: A Nobel Cause. H. J. Schellnhuber, M. Molina, N. Stern, V. Huber and S. Kadner. Cambridge, UK, Cambridge University Press: 49-64.

McDonough, W. and M. Braungart (2002). Cradle to cradle: Remaking the way we make things, North Point Press.

Meadows, D. H., J. Randers, et al. (2004). Limits to Growth: The 30-Year Update, Chelsea Green.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. Washington, DC, Island Press.

Ott, K. (2003). The case for strong sustainability. Greifswalds environmental ethics. K. Ott and P. P. Thapa, Greifswald: Steinbecker Verlag.

Prescott-Allen, R. (2001). The Wellbeing of Nations: A Country-by-Country Index of Quality of Life and the Environment, Island Press.

Raven, P., L. Berg, et al. (1995). Environment, Saunders college publishing.

Speth, J. G. (2008). The Bridge at the Edge of the World: Capitalism, the Environment, and Crossing from Crisis to Sustainability. New Haven, CT, Yale University Press.

Stiglitz, J. E., A. Sen, et al. (2009). Report by the Commission on the Measurement of Economic Performance and Social Progress (Stiglitz Commission).

UNEP (2007). Global Environment Outlook: environment for development (GEO-4), United Nations Environment Programme. http://www.unep.org/geo/geo4/report/GEO-4_Report_Full_en.pdf.

Vallero, D. and C. Brasier (2008). Sustainable Design: The Science of Sustainability and Green Engineering, Wiley.

Wann, D. (2007). Simple Prosperity: Finding Real Wealth in a Sustainable Lifestyle. New York, NY, St. Martins' Press.

WCED (1987). Our Common Future. Oxford, UK, United Nations World Commission on Environment and Development, Oxford University Press.

Weisman, A. (2007). The World Without Us. New York, NY, Picador.

Wilson, E. O. (1998). Consilience: The Unity of Knowledge. New York, NY, Vintage Books.

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[i] From http://www.rainforestinfo.org.au/background/maxneef.htm

[ii] http://en.wikipedia.org/wiki/Genuine_Progress_Indicator

[iii] http://hdr.undp.org/en/media/HDR_2009_EN_Complete.pdf, retrieved 10/5/09.

[iv] http://www.neweconomics.org/projects/happy-planet-index, accessed 12/7/2009. See http://www.happyplanetindex.org/)

[v] http://www.happyplanetindex.org/list.htm, retrieved 5/29/09.

[vi] Quantitatively this means that the derivate of each form of capital with respect to time is ≥ zero.

[vii] My family has participated in the YMCA for many years. The YMCA motto is "Spirit, mind, and body". The message is that these are our most valuable resources, and we participate in the YMCA in order to cultivate them. Spirit, mind, and body are like the three pillars of an individuals strength, much like the three E's (environment, economy, and equity) are the three pillars that give human societies strength. The motto does not mention money or stuff. Yet many people neglect or sacrifice one or more of their three pillars of strength. They often trade spirit for money, for example, or mind for stuff.

[viii] *From http://en.wikipedia.org/wiki/Sustainable_development.

[ix] http://www.panda.org/about_our_earth/all_publications/?12982/The-Barents-Sea-Cod-the-last-of-the-large-cod-stocks

[x] According to http://www.pelicanweb.org/sdsustconcept.html. The article by Bolman that they cite is no longer available online.

[xi] People seem to become either exemptionalists or naturalists at an early age, and in my experience they never switch. In fact, exemptionalists seem incapable of thinking like naturalists, and vice-versa. Thus, the nature of our relationship with nature seems to be deeply rooted in our psyche. When I first started writing this book, I had hopes that I could convince skeptics that we are approaching physical limits and that we need to start living sustainably. But some colleagues expressed skepticism that I would be able to get anyone to change their minds, and later publishers (who should know) voiced the same concern. So I've been forced to change my approach from “aim to convince readers,

including exemptionalists, that we must change the way we live to achieve sustainability" to "give naturalists a firm scientific grounding in the ways in which our society has developed unsustainably, and offer practical guidance for developing solutions for the future."

[xii] http://www.nps.gov/muwo/

[xiii] http://www.mdgmonitor.org/goal7.cfm

[xiv] http://wwf.panda.org/about_our_earth/about_forests/importance/economicforest/, retrieved 1/20/2011.

[xv] http://wwf.panda.org/about_our_earth/about_forests/importance/economicforest/, retrieved 1/20/2011.

[xvi] http://www.myfootprint.org/

[xvii] Note that the curves represent annual values of biocapacity and ecological footprint. Biocapacity is assumed constant, but environmental damage could actually decrease availability of ecosystem services and therefore biocapacity. Cumulative debt is equal to the area under the EF curve, shaded red, while cumulative surplus (labeled "biocapacity reserve") is equal to the area above the EF curve, shaded in green. The year in which the red EF curve intersects the green biocapacity curve is the year when the annual budget is balanced. However, the cumulative ecological debt isn't paid until the cumulative surplus is equal to the cumulative deficit.