1 Concepts for a better world

> Prudent and sustainable use of nature's resources has yet to become a reality. Past approaches have failed because the concept of "sustainability" is so ill-defined. Moreover, sustainability can only be accomplished if the complex linkages within the natural world are valued more accurately. For the future it is therefore vital to improve our understanding of the diverse services of ecosystems and to put a comprehensive conception of sustainability into practice.

What is sustainability?

> The concept of "sustainability" comes from forestry and originally meant something like: using natural resources mindfully so that the supply never runs out. Today, however, the concept is ill-defined; firstly because there are various theories of sustainability and secondly because the word has passed into inflationary use. For that reason scientists now debate what is actually meant by "sustainability" and seek to formulate concrete guidelines for sustainable living and economic activity.

A tricky concept

Nowadays the concept of "sustainability" is a staple of any public debate and is used in an inflationary way. Playing on the positive connotations of the word "sustainability" – much like "peace", "justice" and "conservation" – people tend to use it in every possible context. Industry talks about "sustainable production" and financial services providers offer "sustainable performance". Consumers are urged to "eat and drink sustainably"; music classes support "sustainable child development" and even a warm-water bathing day for senior citizens at a public pool is advertised as "sustainable". Everybody understands "sustainability" to mean something slightly different. The concept tends to be more confusing than clarifying. Depending on the given definition, project or context it takes on a different meaning. But the current inflationary use of the term is not solely to blame for this baffling ambiguity; the fact is, the concept is indeed a blend of different factors. Sustainability is a complex matter. Economic development models, the world food supply, nature conservation, poverty reduction or distributive justice – all these aspects play a part in the sustainability debate. Looking back into the past, however, it is evident that the individual themes were often considered in isolation from one another and studied separately. Depending on the historical situation, certain questions took precedence, and others were put on hold until they in turn had become urgent.

Experts today endeavour to frame plausible theories and models in order to enhance the understanding of all the elements that comprise sustainability. The main challenge for the future is to put the broadly accepted insights of sustainability theorists into practice in concrete societal, political or economic models.

1.1 > The concept of "sustainable" silviculture was introduced in 1713 by the Saxonian chief mining official Hans Carl von Carlowitz in his treatise *Sylvicultura oeconomica*, in which he advocated prudent management of forest resources.

Fear of timber scarcity

The expression "sustainable" or "sustainability" came into use in German silvicultural theory in the 18th century. Back in 1713 the chief mining official Hans Carl von Carlowitz, from Freiberg in what was then the Principality of Saxony, published the forestry treatise *Sylvicultura oeconomica*, in which the principle of "continuously enduring and sustainable use" was discussed for the first time. Von Carlowitz coined the term at a time when many parts of Europe were in need of vast quantities of wood for mining and ore-smelting. Gradually the environs of many mining towns were becoming deforested. Wood shortages were an imminent threat. Even at the start of the 18th century, wood was having to be shipped from far away by river. Von Carlowitz warned that, without wood, people would "suffer great hardship". In his *Sylvicultura oeconomica* he called for the forests to be conserved. People, he wrote, should save wood, conserve forests by sowing and planting trees, and seek "surrogata" or alternatives to wood. All in all, people should only harvest as much wood as could regrow.

The aim of forest management was to achieve the greatest possible wood harvest sustainably – in other words, consistently over time – without overexploiting the forest. Thus, 300 years ago, von Carlowitz was voicing demands which are still crucial to the current sustainability debate. Then, however, the focus was on economic considerations rather than nature and forest conservation per se. That was equally apparent from the composition of the forests, and what was considered sustainable at the time: they tended to be monocultures of tree species of interest to the wood industry rather than near-natural forests. Since the concept of sustainability was originally clearly and narrowly defined, it provided a basis for deriving binding rules. For every tree species, prescribed felling rates were defined, i.e. annual maximum quantities of wood that were permissible to cut in a section of forest.

1.2 > Silviculturists in the state of Minnesota, USA at the end of the 19th century. Wood was in particular demand as a raw material at the time, and vast quantities of it were required for housebuilding in the growing towns.

Too many people – too little food

Not just in Germany but throughout Europe, scholars in the eighteenth century were getting to grips with the finite nature of natural resources, although in this context – unlike in the work of von Carlowitz – there was no discussion of sustainability. An important aspect was how to supply foodstuffs to the growing population. Today it is estimated that the population of Europe as a whole grew from 140 million to 266 million between 1750 and 1850. In England alone, the number of inhabitants swelled from around 7 to 20 million people during the same period.

The British economist Thomas Robert Malthus warned that food production would not be able to keep pace with population growth in future. And if the plight of the poor improved, he wrote, this would lead to further population growth – and hence to a food crisis. Ultimately, the result would be a worsening of overall poverty. One solution, Malthus and others seemed to think, would be to maintain the population figure at a constant level. A few years earlier, scholars like the North German lawyer, Justus Möser, had already argued against smallpox vaccination on population policy grounds. The vaccination, Möser warned, would reduce child mortality so greatly that "the world would become too small for all the progeny of mankind".

The doom-laden fears of scholars like Malthus and Möser did not come to pass. Before population growth in Europe could lead to a large-scale food shortage, the problem was solved by a natural scientist: in the mid-19th century, the German chemist Justus Liebig developed artificial fertilizer, paving the way for a huge increase in the productivity of arable farmland. Just as his precursor von Carlowitz did for forestry, Liebig strove to achieve persistently high yields in agriculture whilst endeavouring not to deplete soil fertility.

Environmental degradation caused by the Industrial Revolution

Thanks to Liebig's invention, the kind of food shortage that Malthus had prophesied for the future never came to pass. On the contrary, the topic that captured the atten-

1.3 > Back in 1892 the richly forested Adirondack Park in New York State was designated a National Park by the US authorities. With an area of 24 000 km² it is almost as large as the island of Sicily.

tion of thinkers and scientists was degradation of the natural environment because, in the late eighteenth and the first half of the nineteenth centuries, Europe was overtaken by the Industrial Revolution: the slow and deep-seated transformation of an agricultural into an industrial society. The world was radically transformed by coal mining, metal smelting, the growth of towns and the construction of barrage dams, highways and railways. One who criticized the devastating impacts of this industrial growth was the US statesman and scholar George Perkins Marsh, who toured Europe in the 1850s and was ambassador at the Italian court in Rome between 1861 and 1882. In many of the locations he visited, he observed how humans were changing and to some extent destroying nature. In 1874 he published his most important work, *Man and Nature: The Earth as Modified by Human Action*, in which he described his observations. Marsh's ideal was the village community which conserves nature in the long term and uses its resources mindfully. He warned that humans were in the process of rendering the Earth, the home of humankind, unfit for habitation. People needed to protect nature out of "enlightened self-interest", he argued. But Marsh also emphasized that it was possible to use natural resources rationally. People have a right to use nature's assets, he stated, but not to abuse them.

Marsh's theories and his drastic descriptions of environmental degradation in Europe had the most momentous impact in his country of birth, the USA. In order to prevent deforestation on a European scale, the decision was made to conserve forests. Initially, protection was given just to some areas in isolation. The year 1892, for example, – 10 years after Marsh's death – saw the founding of the richly forested Adirondack Park in the state of New York. Covering an area of 24 000 km², this National Park, the largest in the USA today, is almost as large as the island of Sicily. At the beginning of the twentieth century, the authorities finally came round to safeguarding forests throughout the country from overexploitation. It was in 1905 that the United States Forest Service was founded, a forest authority whose first Chief was Gifford Pinchot. Pinchot, a forest scientist and politician, was inspired by

1.4 > The US scholar George Perkins Marsh is acknowledged as one of the forefathers of the environmental movement. In the mid-19th century on a tour of Europe he experienced how nature was being destroyed. His drastic descriptions of this overexploitation contributed to the introduction of sustainable forest management in the USA.

Marsh's teachings. He established sustainable forest use in the USA, just as had been advocated by von Carlowitz almost 200 years previously.

Prosperity rather than sustainability?

Apart from a few positive examples, however, the idea of making prudent use of nature stubbornly failed to take off. For one thing, periods of severe deprivation during two World Wars led policymakers in Western industrialized countries to pursue one goal above all else in the mid-20th century: to generate prosperity for all and, through constant economic growth, to overcome absolute poverty and alleviate class disparities. Thus, the dualism of economic growth and sustainability was preordained.

At the beginning of the 1960s, however, there was mounting criticism of this naïve faith in growth and progress. The damage caused by unchecked economic growth took on increasingly vast dimensions. Soils and rivers were being poisoned. Smog was forming in many urban centres from the emissions of cars, factories and power

plants. Children in particular suffered from respiratory illnesses. Sulphur dioxide emissions from power plants and car engines led to the phenomenon of "acid rain", which caused trees and entire swathes of forest to die off. Environmental conservationists talked about "forest death".

In the 1970s, the concept of "sustainability" then underwent a renaissance. It was now defined more broadly than before. Advocates of sustainability criticized the established economic models which insisted that economic growth was an ongoing necessity. In 1972 the Club of Rome published its highly respected study, *The Limits to Growth*, which mentioned a "sustainable global system" for the first time. In its report, the Club of Rome warned against the consequences of overexploitation. It developed a theory which stated that every phase of strong economic growth would inevitably be followed by a major collapse of the system. Resource scarcity and environmental pollution would turn into severe crises and reduce people to living in the most basic conditions well before the year 2100.

Today opponents of this gloomy vision of the future continually point out that there was no shortage of non-renewable resources after all, because new sources of raw materials have constantly been discovered and exploited. On the other hand, many experts today warn about supply bottlenecks for certain metals either because they only exist in small quantities or because individual states have a monopoly over them. Moreover, they say, resource extraction continues to cause the destruction of natural areas. In their view, the Club of Rome's forebodings are perfectly justified.

The Club of Rome's assumption that environmental pollution would definitely increase in line with economic growth has been considered by some critics to have been refuted in the meantime. Some economists asserted that growing prosperity would be accompanied by greater investment in environmental protection. Many European countries and other industrialized countries around the world did indeed succeed in considerably reducing environmental pollution by means of technical measures like sewage treatment plants and filters in power stations and cars – despite the continuation of economic growth. In the light of environmental pollution and degradation on a massive scale in emerging economies like Brazil, China and India, today the warnings of the Club of Rome take on renewed importance. Contemporary China in particular is a textbook example of the environmental destruction and ecological costs that go hand in hand with unrestrained economic growth. The debate between the critics and proponents of growth continues to this day.

1.5 > In 1966 Essen was the first city in Germany to introduce driving prohibitions in order to reduce the pollution caused by smog. But only when power stations and industrial plants were fitted with emissions filters in the 1980s did air quality improve noticeably.

Club of Rome
The Club of Rome is an international non-governmental organization and expert body which was founded in 1968 by leading industrialists, engineers, business experts and academics in order to analyse the negative consequences of economic growth and to develop solutions.

Same rules for all?

From the 1960s onwards, the "underdevelopment" of the so-called Third World was another much-discussed topic. On the one hand there were economists who saw the economic growth and business model of the industrialized nations as an example worth emulating. In their view the national economies of the Third World countries should match, as rapidly as possible, the industrialized countries' standard of development through "catch-up" industrialization and modernization. Support should be provided to them in the form of development assistance. For this, the prototype was the U.S. aid for reconstruction in Western Europe in the immediate post-war period, which had been organized under the **Marshall Plan**. But this policy did not work well everywhere. Moreover, it did not guarantee universal development or that the entire population of a country would share in the resulting prosperity. Therefore, alongside these more capitalist Western models, other models of development emerged. These were overtly aimed at greater ownership by developing countries of their development processes, and at a more socialist policy of redistribution from the top down, for instance by means of land reforms. The aim of development in such models was not primarily higher consumption of goods but was rather oriented towards aspects like education, health or public participation in policy-making processes.

One milestone was the "eco-development" approach of the Dag Hammarskjöld Foundation in the 1970s. This Foundation was named after the Swedish diplomat and United Nations Secretary-General Dag Hammarskjöld, who had lost his life in a plane crash in 1961. The Foundation has its headquarters in the Swedish city of Uppsala and has continued to organize international conferences and seminars at which experts debate themes of policy such as security, democracy and development. At that time the Dag Hammarskjöld Foundation proposed guidelines on the future of developing countries, which comprised the following aspects:

- Satisfaction of basic needs largely on the basis of own resources;
- Not a copy of the Western lifestyle and pattern of consumption;
- Conservation of the environment;
- Respect for cultural difference and local traditions;
- Solidarity with future generations;
- Use of technologies adapted to local conditions;
- Participation of all population groups and particularly of women in societal and political decisions;
- Family planning;
- Some decoupling from the global market and development of local markets;
- Orientation to religious and cultural traditions;
- No admittance to the military power blocks of NATO (North Atlantic Treaty Organization) and the **Warsaw Pact**.

These early guidelines already cover key elements of the current sustainability debate.

Far more than silviculture and pollution control

While sustainability was originally applied to forestry alone, this was later joined by aspects like population growth, food, and environmental protection. Since the 1970s, aspects of society have increasingly come under the spotlight of the sustainability debate – for instance, the question of how different stakeholder groups can participate in societal and political decisions, or to what extent people today are responsible for the well-being of future generations. Against this backdrop, in 1980 the United Nations (UN) convened the World Commission on Environment and Development (WCED). It was tasked with finding ways to achieve several major objectives simultaneously, namely:

- to fight poverty in developing countries;
- to support developing countries in development in keeping with their traditions;
- to master environmental challenges;
- to level out the contrast between Western market economics and state socialism.

In 1987 the Commission presented its report, which was named the Brundtland Report after the Commission's chairwoman, the then Norwegian Prime Minister, Gro Harlem Brundtland. Its underlying idea was that the satisfaction of basic human needs should have priority over all other objectives. This "basic needs" approach was also taken into the definition of sustainability used in the WCED report, which read: "Sustainable development is

development that meets the needs of the present without compromising the ability of future generations to meet their own needs." No definition of sustainability has been quoted as frequently as this one. This wording contains the important demand that meeting human needs should be kept within the carrying capacity of the natural environment.

The Commission chose the phrasing "sustainable development" at least partly in an effort to pull together the different and in some cases competing objectives of environmental protection, poverty reduction and economic growth. Its use of this definition was an attempt to integrate some of the divergent ideas on the pathways that developing countries might take in future. The phrasing "sustainable development" was intended to help:

- to take account of the idea of the developing countries' ownership of processes without veering too far towards socialist ideals;
- to draw attention to the ecological limits to growth;
- not to lose sight of the old UN objective of fighting poverty;
- not to fundamentally challenge Western lifestyles;
- to address the challenge of population growth.

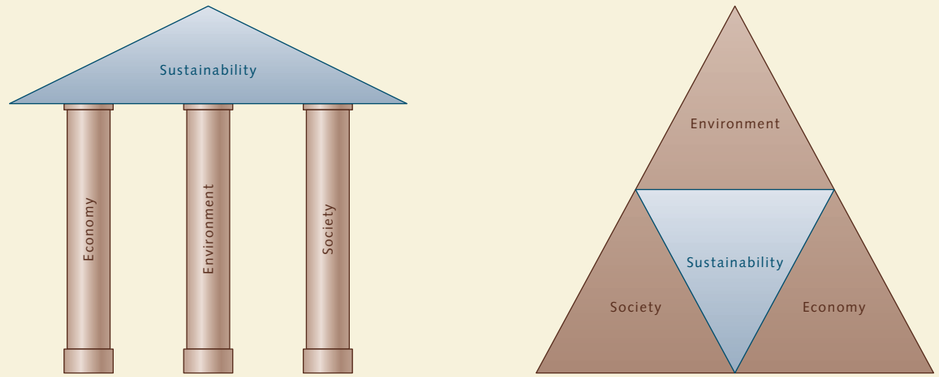
All in all, the Commission wished to define the lowest common denominator of sustainability that all its members could accept. The result was a compromise formula. A further aim of the WCED report was to bring the theme of sustainability into the public sphere. That was accomplished. The report was quite catalytic in sparking a new debate about the meaning of sustainability. What it did not provide were concrete directions for political intervention. The problem with the concept of "sustainable development" and the entire WCED report is that the wording of the definition was a compromise solution which left it open to completely different interpretations by different stakeholder groups, by politicians or by industry. Hence, the WCED report contains no systematic conception of sustainability. This is a key reason why the sustainability concept has remained so vague in the political discourse until now.

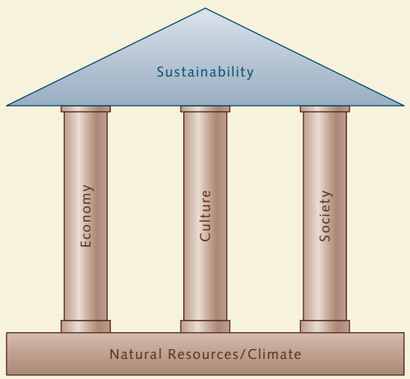
Following the publication of the WCED report, many countries embraced the idea that sustainability could be achieved by striving for the objectives framed by the Commission – poverty reduction, equitable economic growth and environmental protection – in equal measure. Taking that as a basis, theorists derived what is known as the "three pillars" model. According to this model, sustainability rests evenly on the three pillars of the environment, the economy and society, all three of which rank equally in stature. However no clear verdict is given as to whether this equal ranking is the case already, or whether it first has to be accomplished. Critics also object that the sustainability concept incorporates a normative dimension. In their view, sustainability is more than a philosophical theoretical model because ultimately, such a theory ought to make it possible to derive clear directions for action and to implement appropriate measures.

Responsibility for posterity

Making mindful use of resources over the long term to ensure that they will still be available in future is one of the pivotal ideas of sustainability. So sustainability ties in very closely with the responsibility of generations living today for the future. How far this responsibility extends has long been a matter of contention. In the 1970s, a few scientists defended the view that the generation living in the present day had absolutely no responsibility for those born later. The argument was as follows: unborn persons do not exist, are not therefore legal entities and thus cannot have rights of any kind whatsoever. On that basis, the living have no obligations towards the unborn. Today, however, this extreme perspective has few if any adherents. The very fact that future persons will have rights, the critics contend, is sufficient to permit obligations to be derived for people alive today. These obligations would not relate to particular unborn individuals but in a general way to generations of human beings living in the future. It follows that intergenerational distributive justice is an essential component of sustainable development. What legacy, or how much present-day humankind should leave for posterity, is nevertheless a debatable issue.

The classic and the extended "three pillars" model





1.6 > In the classic three pillars model, the environment, the economy and society are represented as three columns of equal stature supporting sustainability. The aim of this model, developed at the end of the 1990s, was to pave the way for sustainable development. Its underlying assumption is that economic, social and environmental concerns are interconnected and form an indivisible whole for the purposes of sustainable development. One refinement is known as the weighted three pillars model. In order to underscore the great importance of the environment, in this scheme it is represented as a foundation, formed by two factors: natural resources and the climate. Resting on this foundation are the pillars of the economy, society and – a new addition – culture. In the past 20 years, numerous other modifications of the three pillars model have been developed. One criticism levelled is that the classic version shows the environment, the economy and society as having equal standing, but does not make this a reality. Even now, the critics point out, in many cases economic concerns still take precedence over environmental or social aspects.

Quest for the equitable standard

There are many possible answers to the question of what obligations people living today have towards generations yet to come – depending on the chosen reference standard. For example, scientists make a distinction between the comparative versus the absolute standard. According to the comparative-standard model, people of future generations should be no worse off overall than the people alive today. But that immediately raises the question of whose living standards will be used for comparison – those of people in the industrialized countries or in developing countries? People's living standards can differ substantially even within the industrialized countries or emerging economies themselves. So defining a single global comparative standard is very difficult, as every basis for comparison seems arbitrary.

The absolute standard, on the other hand, stipulates minimum requirements which are fundamental elements of a life in human dignity. This absolute standard should be valid for all human beings without distinction; that includes those still to be born. Nevertheless, an absolute standard that only requires basic needs to be met is quite a low standard.

Today's reality is that a plausible absolute standard for all does not yet exist. After all, millions of people worldwide are still living in conditions of severe hardship, lacking food, clean drinking water or access to education. This realization can cause an over-emphasis on combating poverty through economic growth in emerging economies and developing countries, which detracts from the importance of conserving natural resources over the long term as a policy of sustainability would demand.

Today the prevailing opinion among sustainability theorists is that neither the comparative nor the absolute standard alone is sufficient as a yardstick for sustainability models, for in reality living conditions around the world are just too disparate at the moment. Nor do the experts see any reason to believe that in the medium term it will be possible to raise living standards in poor developing countries, such as Bangladesh for instance, to the same level as rich industrialized nations like Switzerland. It is therefore more pragmatic, they say, to define regionally differentiated standards. Thus, it would make sense to work towards one good, absolute standard for the developing countries and emerging economies, on the one hand; over and above this, on the other hand, different comparative standards are practicable for more highly developed regions and may vary from country to country or region to region.

1.7 > A slum in Dhaka, the capital of Bangladesh. Millions of people in the world live without clean water, sanitation or access to education.

This does not in any way mean that living conditions in the given regions are expected to stay the same forever. Modern sustainability models are very much geared towards reducing absolute and extreme poverty, as well as tackling the extreme disparities between the rich and the poor. A distinction needs to be made between these two goals. For as the example of China shows, it is possible for poverty in a country to lessen generally even though major disparities in income and wealth exist. Poverty in China's rural regions is receding whilst at the same time a prosperous middle class is emerging in the metropolitan centres with significantly higher incomes than the rural population.

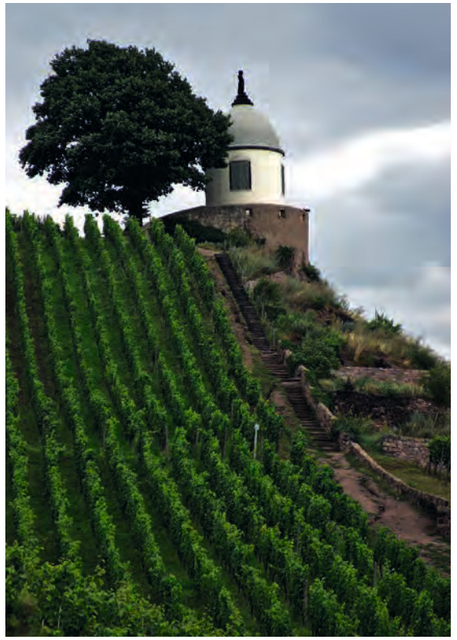
Sustainability theorists advocate reducing absolute poverty first and foremost, arguing that that is the paramount goal. They accept that some responsibility must be taken for the future, but responsibility for the present is their most immediate concern. To concentrate on the future while ignoring present-day hardship, they say, is to set the wrong priorities. So far, theorists are still at odds over the extent to which economic inequality can be permitted to exist at all.

The great goal: a life worth living

As an answer to the question of what constitutes a life of human dignity, the "basic needs" approach has been cited since the 1980s. However, this comprises only the absolute essentials of survival, particularly food, clothing and shelter. Far more ambitious is the capabilities approach which was developed around ten years ago by the US philosopher Martha Nussbaum. This contains a list of capabilities which are said to enable anybody to live a life according to their own ideas. The list relates both to the people alive today and to future generations, and proposes that every person should be capable of

1. being able to live to the end of a normal human lifespan and not having to die prematurely;
2. being able to have adequate nourishment, shelter and good health, and being able freely to express their sexuality;
3. being able to live without unnecessary pain and suffering;
4. being able freely to exercise imagination, thought and logic and to practise a religion;
5. being able to maintain attachments to things and people and to experience and cherish interpersonal values like love, care, gratitude but also longing and grief;
6. being able to form their own conception of a good life and plan their own life;
7. being able to engage in social interaction and to experience recognition, community, friendship and professional life;
8. being able to live well in relation to animals, plants and the world of nature;
9. to be able to laugh, engage in recreation and experience enjoyment;
10. being able to participate politically, freely carry on an occupation under fair working conditions, and acquire property.

This list includes aspects which go far beyond the definition of an absolute material living standard. In fact, it comprises all those capabilities which universally characterize quality of life and human dignity. Naturally, the capabilities approach is first and foremost a theory-of-justice model that was developed by philosophers. Ultimately it is the responsibility of countries to ensure that their citizens can develop and exercise all of the capabilities. Looking at the living conditions in developing countries, however, fulfilment of this standard for all people still seems a very remote prospect. This is not a complaint against the capa-



1.8 > A hillside vineyard in Radebeul near Dresden. Economists assign vineyards to the category of cultivated natural capital.

bilities approach, though, but much more against the political and economic circumstances. One strength of the approach is that it contains a list of aspects which are transferable to all cultures. Over time, the capabilities approach has been taken into account in many UN documents. It has thus established itself as an important basis for the political discourse about the responsibility of those alive today towards the people of the future.

If we follow the capabilities approach, the question is which things people alive today should bequeath to future generations to ensure that the people of the future can likewise attain the 10 capabilities and live fulfilled lives. Experts talk about this in terms of a "fair bequest package". For a good education, people need libraries, for the transportation of goods they need roads, for food production they need fertile farmland, for clean air they need forests. Beyond this, the fair bequest package also includes natural landscapes, which are all the more important because people can only develop the capability to enjoy nature by experiencing these landscapes themselves. This capability is in no way a luxury for human life but is accepted as one of the basic ideas of a good life.

Capabilities like the capacity to enjoy nature may appear abstract. But they are all linked to a concrete resource. The capability to engage in recreation, for example, presupposes that there are forests to walk through, beaches for bathing, and urban green spaces where people can relax. Economists refer to such resources as different types of "capital":

1. real capital (machines, factories, infrastructure);
2. natural capital (forests, oceans, rivers, coasts);
3. cultivated natural capital (commercial forests, livestock herds, vineyards, agricultural land, aquacultures);
4. social capital (political institutions, social cohesion, sources of social solidarity);
5. human capital (skills, education);
6. knowledge capital (libraries, universities).

In the sustainability debate, the natural forms of capital are of greatest importance. These are characterized specifically as follows:

- renewable or self-regenerating resources (for example, plants and animals) and non-renewable resources (for example, metal ores, petroleum);
- original natural capital (unregulated rivers, primary forests) and cultivated natural capital reshaped by human activity;
- sources (for example, minerals from the mountains), sinks (for example, the ocean as a carbon dioxide reservoir) and stocks (for example, animal populations).

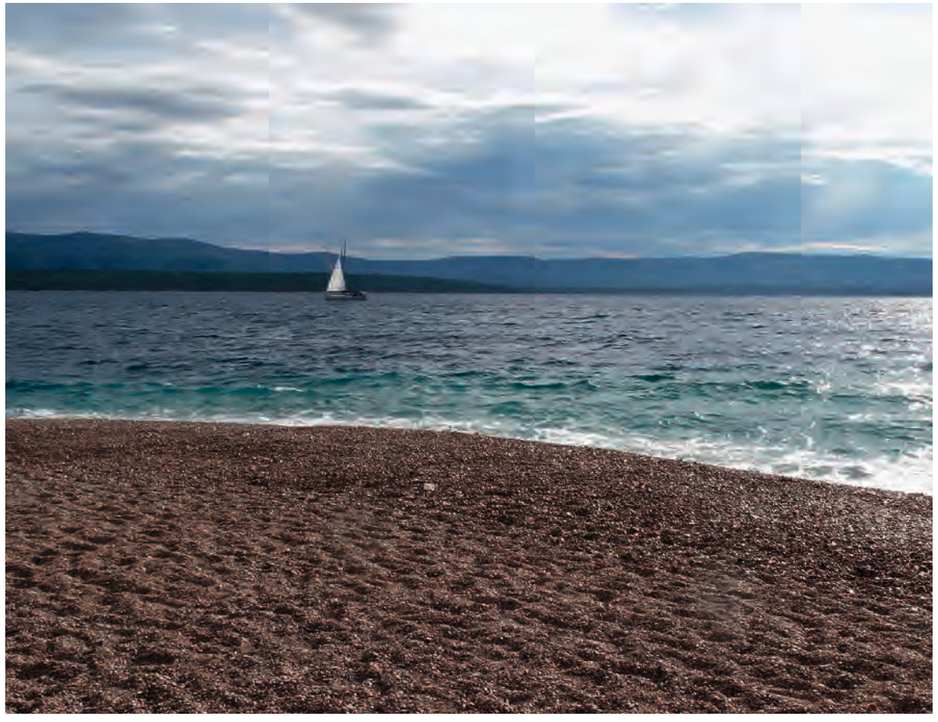
Today sustainability theorists increasingly emphasize that the various forms of natural capital encompass not only material but non-material values, such as the recreational effect of beaches and forests. The theorists talk about the welfare effect of natural capital and emphasize that the degradation of natural capital goes hand in hand with the loss of such values.

Weak versus strong sustainability

To what extent certain forms of capital, particularly natural capital, should be conserved for posterity has long been a contentiously debated issue. Since the 1970s, the debate has circled around the following two contrasting models: the model of weak sustainability and the model of strong sustainability.

According to the weak sustainability model, only the sum total of a society's capital stocks needs to be held constant. By that standard, it is possible for capital resources that have been consumed to be replaced with different types. In principle, then, there is unlimited scope for substituting natural capital with real and human capital. Under the weak sustainability model, these substitution processes are permissible almost without restriction. Even destroyed elements of natural capital, such as rivers that are biologically dead due to pollution, can be replaced under this model. The recreational function of river bathing, for example, can be substituted by constructing open-air or indoor swimming pools; obtaining drinking water not purely from groundwater but alternatively from desalinated seawater; or replacing the aesthetic quality of natural landscapes with artificial, virtual worlds. According to the model of weak sustainability, all that matters is to satisfy the sum total of people's needs – irrespective of which type of capital is utilized.

Particularly in the 1970s, a period of great environmental degradation, many economists believed in the idea of weak sustainability. Some of its proponents note that



1.9 > The Golden Horn, one of Croatia's most popular beaches. Not just the Adriatic but every sea in the world has so many different functions that it can never be substituted in full. The recreational function is one of these.

critical natural capital stocks – i.e. stocks that are very difficult to substitute – are indeed worth conserving. When a form of natural capital should be classified as critical is often a matter of dispute, however.

Strong sustainability for environmental quality

While some economists still stick with the model of weak sustainability, scholars in other scientific disciplines consider it a write-off: today it is generally accepted that not every form of natural capital is indiscriminately substitutable. If we consider the scale and the consequences of the destruction of natural capital today, the limits of substitutability become very much clearer than in economic models. This is particularly true of multifunctional natural capital, i.e. forms of capital which fulfil several functions simultaneously. Oceans, for example, supply food, are an income source for fishers or aquaculturists and a recreational zone for millions of tourists. Completely replacing the multifunctional habitat of the ocean is impossible – hence, the idea of substitutability is obsolete. A similar argument is valid for forests with their many functions.

Over the last few years, therefore, the "strong sustainability" model has gradually gained ground in sustainability theory, and is becoming increasingly widespread in the political sphere. The aim of strong sustainability is to conserve natural capital, regardless of whether and to what extent it is substitutable or how other capital stocks such as real capital (for example, in the form of industrial and consumer goods) might develop. In keeping with strong sustainability, natural capital has to be conserved because of its many different functions – not only because of its material values, but also its cultural values, for example.

So the question is not just whether natural capital can be substituted but, more importantly, whether humankind actually desires a permanent substitution now and in future. The generation living today cannot judge what needs and cultural value ideals future generations will have, and whether those yet to be born are in agreement with the substitutions we make today. Substitution of natural capital, in other words ultimately the loss of natural habitats and the decline of biodiversity, is irreversible and scarcely justifiable. If natural capital is consumed today, it no longer remains available as an option to the people as yet unborn. In that case, generations to come no longer have the choice between natural capital and the substitute, but have to live with the substitute.

Since the strong sustainability model decrees that present-day amounts of natural capital should be held constant, it means that the destruction of natural habitats and degradation of environmental systems must be halted.

Modern sustainability models try to reconcile the economic use of natural capital with its conservation. To make this possible, however, a few rules are necessary. One example is known as the Constant Natural Capital Rule (CNCR) which requires maintaining the sum total of natural capital. This in no way implies a kind of museum-style nature conservation which totally prohibits any modification of near-natural areas. In fact, the CNCR's aim is the conscious use of natural capital and, above all, the substitution of consumed natural capital with other natural capital of equivalent value.

It is important to emphasize that according to the CNCR there is not just one way to replace natural capital. Strong sustainability does not force any ideal path upon policymakers from which they must never stray. Rather, the CNCR requires people to be creative in seeking good solutions for any substitution of natural capital. Thus, a harvested tree might be replaced with a tree of a different species. It is even conceivable that a certain forest biotope might be substituted with another. In some cases, near-naturally managed forests could fulfil the functions of destroyed virgin forests. It may also make sense to build up natural capital in the form of plantations if virgin forests elsewhere might be protected as a result.

The CNCR represents a modern, flexible and practicable rule of strong sustainability which can be used to resolve conflicts over use. The major difference from weak sustainability is that according to the CNCR, consumed natural capital must be replaced by equivalent natural capital. The CNCR approach does not allow substitution with real capital, nor exclusively technical solutions, as in the substitution of clean river water by water from seawater desalination plants.

The multilevel model – a bridge between academic theory and operational practice

In recent decades, German scientists have sought to establish a comprehensive perspective on "sustainability". Basic theories rooted in philosophy and ethics were linked with economic theories and knowledge from the natural sciences.

A notable example is the multilevel model developed in the 1990s. It was devised by its authors as a multi-stage process consisting of discrete mental building blocks, referred to as levels. Its aim is to derive concrete actions and measures from sustainability theory and to create a bridge between sustainability theory and real environmental policy.

- On the uppermost level, the ethical principles of the sustainability idea are reflected. Here it is also clarified how far people bear a responsibility towards subsequent generations and how through their behaviour, they influence the life-support base of their descendants. This discourse concludes with the demand that people living today are obliged to preserve a legacy which enables future generations to meet their own needs.

- On the second, strategic level there is discussion of what makes up such a legacy, i.e. which assets, resources and forms of capital should be preserved on what scale. At this point the authors speak out in favour of a strong sustainability model because natural capital cannot be substituted indiscriminately.

- On the third level, a framework of rules for sustainability is drafted. Top of the agenda here is the Constant Natural Capital Rule (CNCR), which imposes the obligation to conserve natural capital over time. Essentially only as much natural capital should be consumed as nature can replenish. Examples are the use of renewable energies instead of fossil fuels or the prudent management of fish stocks. For regions which were subject to large-scale destruction and consumption of natural capital in the past, an investment rule applies, its purpose being to correct as far as possible the overexploitation and mistakes of the past. The recultivation and restoration of previously degraded natural areas belong under this heading. Other management rules specify exactly whether and how much natural capital may still be used in future.

- The fourth level defines three normative guidelines for sustainable action. These guidelines are efficiency, sufficiency and resilience. Efficiency relates to the economy. It requires modern, more efficient technologies to be developed; for example, engines with higher energy-conversion efficiency. Sufficiency is addressed to a sustainable lifestyle. On the one hand it demands that all people worldwide should be enabled to meet their basic human needs. It sets the industrialized countries the target of striving for a lifestyle with the least possible consumption of raw materials and energy. According to this guideline, the industrialized countries are called upon to develop post-materialistic prosperity models. This is not in any way about forcing people into an ascetic way of life. Rather, it revolves around the rejection of individual utility maximization, or creating islands of deceleration and blurring the rigid boundaries between work and leisure. Resilience relates to the conservation of natural capital itself, but also to maintaining the various functions that such capital has, such as recreation. Generally resilience refers to the capacity of a habitat to withstand disturbances. Previously damaged habitats are often less resilient. One aim is therefore to protect habitats accordingly.

- On the fifth level policy-making and action areas are defined in which sustainability is to be achieved. These include areas like nature conservation, agriculture and forestry, fisheries and climate change. Such a breakdown into different areas is important in order to be able to plan and implement measures as specifically as possible.

- On the sixth level, goals are derived in the most concrete possible terms. For example, it has been resolved to reduce the discharge of nutrients into the Baltic Sea by 50 per cent in the next few years. But it is not always possible to specify a precise target value, as it can be unclear at what value sustainability is reached. For example it is not necessarily possible to determine how high the share of dead wood should be in a sustainably managed, near-natural forest. In such cases, a kind of target zone, a broader corridor of targets, can be defined. As a matter of principle, diverse stakeholder groups should be involved in setting target values.

- On the final level, instruments are developed to support the achievement of concrete sustainability goals, along with monitoring systems to help verify whether these have actually been attained.

The value of nature

> If people intend to make prudent and sustainable use of natural resources, they must determine in what manner and to what extent they wish to utilize the natural world or conserve it. This is only possible if they can make an accurate assessment of the costs and benefits. It can be helpful in this context to look at nature in economic terms as natural capital. Nevertheless, it is highly problematic to put a value on the services of nature.

Nature – a gigantic service provider

For time immemorial nature has been providing human beings with the resources they need for survival; things like fruits, grains, fish, meat or wood. It also puts a free supply of clean air and clean water at our disposal. Economists group all these aspects together under the heading of natural capital. In simplified terms, natural capital is defined as the stock of natural assets such as the soil, forest or ocean, which generate natural products and services such as fresh air or potable water.

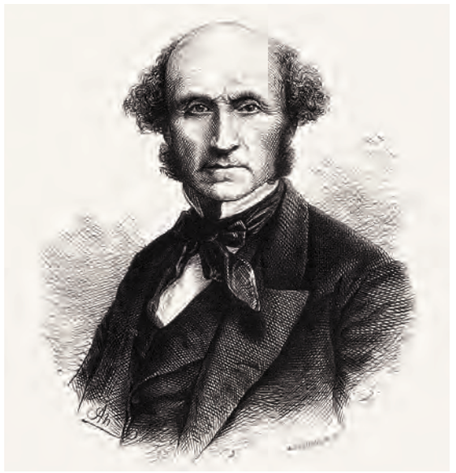
Measured against the several-centuries-old history of economics, the concept of natural capital is still very new. It was only coined in the second half of the 19th century. Until then, economists took nature and its services for granted. The sole exception was fertile agricultural soil. Before the invention of artificial fertilizers, the fertility of soils and hence their yield was limited. The productivity of farmland could not be increased at will because the quantity of nutrients was limited. Since adequate food had to be produced for the population nevertheless, large areas of land had to be farmed, and the number of people working in agriculture was very high.

After the German chemist Justus Liebig had invented artificial fertilizer in the mid-19th century, the situation changed. The productivity of farmland was increased several times over. Fewer farmers could harvest more crops. This released workers who were needed in the factories of the growing industrial towns. The importance of soil as an economic factor diminished. Instead, many economists came to consider real capital, in the form of machinery and infrastructure, as the only factor determining economic growth.

1.10 > One of the first blast furnaces, in Coalbrookdale, England, in the year 1801. During the Industrial Revolution a paradigm shift took place in economics. Many experts lost sight of the significance of soil and the services of nature as economic factors. Only the investment of real capital was thought to determine economic growth.

Never-ending harvest?

Very few thinkers gave more sophisticated consideration to nature and its services. Among them was the English philosopher and economist John Stuart Mill, who emphasized in the 1870s that nature ought also to be preserved for the sake of its intrinsic charm. Mill wanted to halt population growth. He feared that humankind would continue to destroy near-natural, aesthetic landscapes if the human population continued to expand.



1.11 > The English philosopher and economist John Stuart Mill noted in the 1870s that nature would suffer further destruction unless population growth was halted.

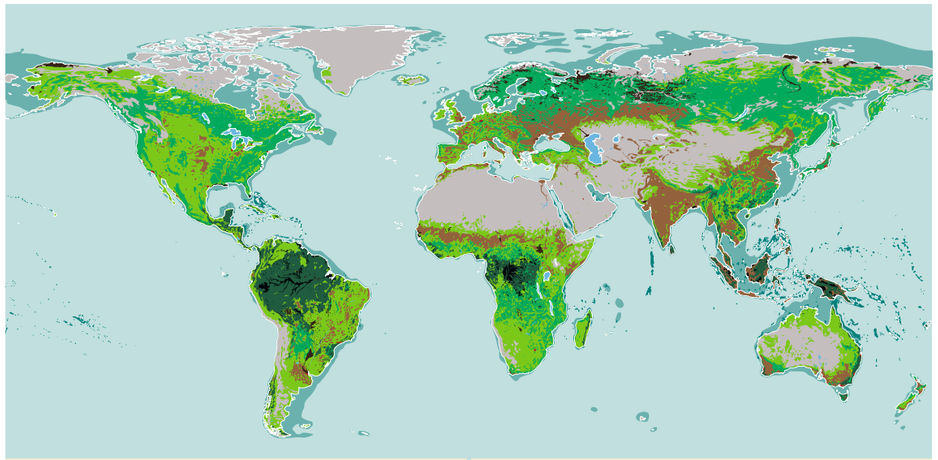
At this time more concrete work was being done by the French economist Léon Walras, who published his *Elements of Pure Economics, or the Theory of Social Wealth* in 1874. Among other issues, he deals at length with the services of nature in his work, and develops the concept of natural capital. Walras, too, initially considers nature as an inexhaustible source because in his view natural capital cannot be destroyed entirely. On the contrary, he says, year after year it keeps supplying new products. Walras refers to this fertility of nature as a service, and to the yields that agriculture produces as "rents". However, Walras recognizes that natural capital, like other forms of capital, can become scarce and that its value rises as a result: "the quantity of land can be very limited in an advanced society, relatively to the number of persons […] and has a high degree of scarcity and value". Walras makes further distinctions and writes that natural capital can be used in two ways: firstly, as existing capital stock from which long-term income is generated – for example, an apple tree that provides fruit for many years – and secondly, as capital that is used directly – for example if someone cuts down the tree and sells the wood. Walras's approach was extraordinarily modern in its analytical breakdown of the concept of natural capital. Even today, experts still make a similar distinction between stock and flow variables – in other words, between natural capital that is used and consumed directly, and natural capital that provides a continuous flow of rents over a longer period of time.

Despite Walras's publications, natural capital played no part in economic theory for around another 100 years because economists were convinced that there could be no absolute scarcity of natural capital.

Is the value of nature measurable?

Today the concept of natural capital is well established. Even so, how the value of nature should actually be estimated is still a contentious issue. This question is important when it comes to quantifying the losses caused by progressive degradation of nature or assessing whether it is economically viable to invest in natural capital. Investment projects of this kind may include the restoration of degraded natural landscapes to a more natural state, or the near-natural management of forests. The valuation or monetization of natural capital is a huge challenge, particularly because natural capital does not take just one but many different forms – forests, rivers, meadows or the ocean. And all of them provide different services.

1.12 > World map with the different ecosystem types and the calculated values of their ecosystem services (in US dollars per hectare per year).



Ecosystem types	A	B
Desert, tundra, ice and rock	4232	0
Open ocean	33200	491
Coastal and shelf areas	2660	2222
Grass and pastureland	4418	2871
Forests in temperate and northern latitudes	3003	3013
Rivers and seas	200	4267
Rainforest	1258	5264
Arable land	1672	5567
Conurbations	352	6661
Floodplains and swamplands	60	25682
Salt marshes and mangroves	128	193845
Coral reefs	28	352249

A: Size of area in millions of hectares, B: Monetary value per hectare per year in US dollars

Ecosystem service

Economists and sustainability theorists call any service that nature provides an "ecosystem service". Examples are the availability of potable water, fresh air, or food in the form of fish and fruits. Added to these are aspects which are not directly measurable like the beauty of a landscape that provides people with recreation. "Natural capital", in turn, denotes the natural resources which produce all these ecosystem services.

In 1997 a team of American scientists and economists published a study in which they attempted to document the total value of services provided by all **ecosystems** worldwide. They came to the conclusion that global natural capital including these various ecosystem services generates 33 thousand billion US dollars per year – almost twice as much as **global gross national income** which amounts to 18 thousand billion US dollars. In this study, the oceans accounted for the lion's share, valued at 21 thousand billion US dollars.

For their study the scientists had divided the globe into around 20 ecosystem types and seventeen ecosystem services, such as climate regulation, water storage or food production. Subsequently, for every ecosystem and every service they determined the value of one hectare and then calculated projections for the total global area. In 2011 a new study was presented in which the data from 1997 was re-evaluated and the ecosystem services updated. One of the most important findings of this study was that because of land-use changes, the value of ecosystem services had fallen from 1997 to 2011 by at least an average of 4.34 thousand billion US dollars per year. Land-use changes are processes like the conversion of tropical rainforests and wetland areas into productive agricultural land.

There was massive criticism of these studies. Experts complained that the projections were unreliable because they drastically oversimplified matters and did not adequately take account of the diversity of ecosystems. Another criticism was that having arrived at a figure, it was completely unclear which political consequences were to be drawn from it. Thus the studies provided no action guidelines on which natural capital ought to be protected or how. Although the first study appeared in the respected scientific journal *Nature* in 1997, today it is viewed less as a profound scientific paper and more as a politically motivated publication. As such, the experts say, it is significant because it showed for the first time what order of magnitude the value of natural capital can actually reach.

Ecosystem service*	Ecosystem functions	Examples
Gas regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels
Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation, DMS production affecting cloud formation
Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure
Water regulation	Regulation of hydrological flows	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation
Water supply	Storage and retention of water	Provisioning of water by watersheds, reservoirs and aquifers
Erosion control and sediment retention	Retention of soil within an ecosystem	Prevention of loss of soil by wind, runoff, or other removal processes, storage of stilt in lakes and wetlands
Soil formation	Soil formation processes	Weathering of rock and the accumulation of organic material
Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients	Nitrogen fixation, N, P and other elemental or nutrient cycles
Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations.
Biological control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction of herbivory by top predators
Refugia	Habitat for resident and transient populations	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds
Food production	That portion of gross primary production extractable as food	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing
Raw materials	That portion of gross primary production extractable as raw materials	The production of lumber, fuel or fodder
Genetic resources	Sources of unique biological materials and products	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants)
Recreation	Providing opportunities for recreational activities	Eco-tourism, sport fishing, and other outdoor recreational activities
Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems

* We include ecosystem "goods" along with ecosystem services.

1.13 > In order to assess the total value of services provided by all ecosystems worldwide, in 1997 US researchers defined various ecosystem service categories. Although the study was criticized because it massively simplified the worldwide situation, it was nevertheless a milestone because it made clear the vast overall economic significance of ecosystem services in their entirety.

Different types of services

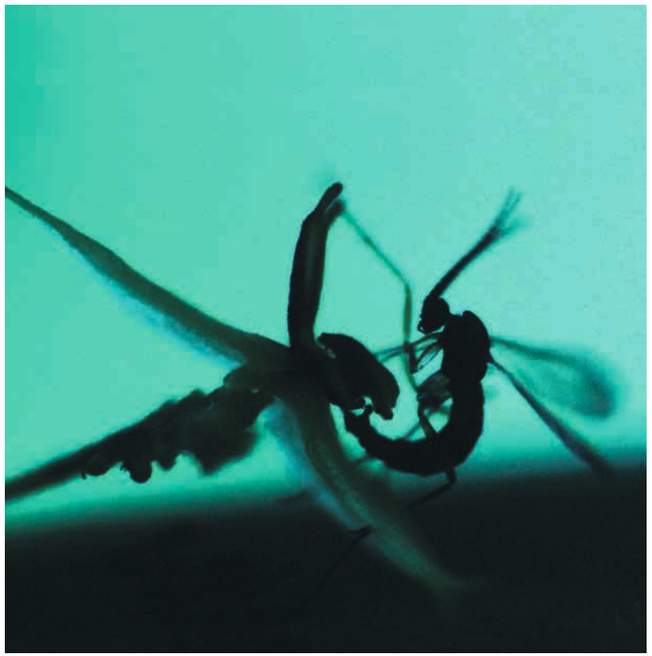
The publication of the study in 1997 prompted the question of whether it was even permissible to give natural capital a monetary value. One of the arguments voiced was that natural capital is vital to human survival, irreplaceable, and hence of infinite value; monetization was inappropriate. Very few experts still defend this extreme position today. Nowadays only "primary values" which represent the basis for life on Earth – such as solar radiation, fresh water or atmospheric oxygen – are considered to be non-monetizable. Putting a price on such primary values would make little sense.

What is certain is that a monetary value can only be applied to natural capital if it is considered on a smaller scale. Thus it is virtually impossible to determine the value of the sea in its totality, but very much easier for a particular marine region or a specific service. Before one can even attempt to value natural capital, it must first be categorized. The United Nations (UN) launched an attempt to do so in 2001 with the major international project, the Millennium Ecosystem Assessment (MEA), in which several hundred researchers analysed all ecosystems worldwide and allocated them to different categories of services:

- Supporting services, which maintain the ecosystem itself, such as nutrient cycles or genetic diversity;
- Provisioning services, which produce food, water, building material (wood), fibres or pharmaceutical raw materials;
- Regulating services, which regulate the climate, ensure the absorption of wastes and air pollutants, or are responsible for good water quality or for plant pollination;
- Cultural services, which facilitate recreation, nature tourism, aesthetic pleasure and spiritual fulfilment.

Although such a breakdown can be helpful for the monetization of natural capital, many ecosystems and the multitude of interrelationships among living organisms are so complex that their significance and performance, and hence their value, cannot be captured in their entirety. It is hard for scientists even to assess what consequences might result from the disappearance of a single animal species, such as a predatory fish species, let alone the destruction of an entire ecosystem. Orchids in the rainforest, for example, are found to be pollinated by one sole insect species in some cases. If the insect is lost, the orchid dies out, and this in turn affects other animal species which are dependent on it. If this relationship goes unrecognized, the value of the insect species will be underestimated.

The valuation of ecosystems is also complicated by the diverse ways in which they are interwoven and reciprocally influence each other. Researchers are often virtually unable to discern these dependencies – and hence also the services that ecosystems provide for one another. A mountain forest, for instance, stabilizes the soil. If the mountain forest dies, erosion escalates. Soil is washed into streams and rivers, which also affects the living conditions for marine organisms in coastal waters.



1.14 > Part of the flower of the orchid species *Lepanthes glicensteinii* is shaped like the genitalia of a female fungus gnat. Deceived into copulating with the flower, the male picks up pollen, with which it subsequently pollinates other plants – an example of a regulating ecosystem service.

The value of nature – today and tomorrow

Thus, in order to be able to assess the value of natural capital in a manner that captures the linkages and dependencies, even finer differentiations must be made. Economists attempt to do so by assigning the ecosystem services of nature to different value categories. The total value of any given natural capital is then obtained from the sum of all its services – experts talk about the Total Economic Value (TEV) of an ecosystem. Under the TEV approach, an initial distinction is made between the use value resulting from the use of the natural capital, and the non-use value which the natural capital represents in itself. The use value and non-use value are then broken down still further.

The use value includes:

- the direct use value, provided for example by a fish that has been caught. This value can be expressed in concrete terms for any given service in the form of a market price;
- the indirect use value, such as the climate-regulating effect of a forest, or the sea, or natural water purification in the soil;
- the option value which arises through any potential future use of the given natural capital; for example, pharmaceutical ingredients which are obtained from marine organisms.

The non-use value includes:

- the existence value that human beings attach to creatures like blue whales or to habitats like mangrove forests, without necessarily thinking that they will be able to use or even experience these habitats themselves in future. The existence value arises from the sheer delight of knowing that these creatures or habitats exist;
- the bequest value, which exists because people feel the desire to pass on natural resources as intactly as possible to subsequent generations.

The MEA and TEV are related approaches. Thanks to the two, the significance of ecosystems can better be assessed today, although both only classify rather than supplying any concrete monetary values. While the objective of the MEA was to gain an overview of global ecosystems and ecosystem services, TEV makes much finer distinctions in respect of these services. TEV results in a better assessment not because it combines all values into a composite value, but rather because it takes account of different value categories in the first place. This makes it possible to compare the significance of different ecosystem services with one another.

Today it is known that many ecosystems, and hence also forms of natural capital, are in poor condition. As an approach to improving the situation, however, it makes little sense to establish some total value of natural capital in monetary terms. The pertinent question is rather, which measures might be used to prevent the destruction of an ecosystem, or how its condition might be improved. Normally a host of concrete measures are available for this purpose, which must be weighed against each other. As part of this, prior categorization of the ecosystem services using TEV is helpful.

For example, for several years now the British Department for Environment, Food and Rural Affairs (Defra) has been using TEV for the valuation of nature conservation measures such as the restoration of bird sanctuaries. Furthermore it makes use of TEV in order to study what difference parks and green spaces make to the general health of the population by providing space for recreation, sport and outdoor exercise.

Clearly the management or conservation of parks and green spaces costs money. Moreover, it means that this land is unavailable to be built upon. But the Defra studies conclude that the gain for the population is substantial because outdoor exercise prevents illnesses. They find that a single park in an urban area saves the health system annual costs amounting to 910 000 pound sterling (around 1 150 000 euros) on condition that 20 per cent of the town's citizens make use of the green spaces. Thinking this through, it becomes clear that the total value of natural capital at the present moment is not as relevant to its

valuation as the value resulting from changes. The smaller the available park area, for example, the greater its relative value becomes because fewer and fewer square metres are available for the benefit of those seeking recreation. What is important in this context is the size of the park area to begin with. Thus, the loss of value is much greater if a few square metres are deducted from a small area of parkland than from a huge park. Equally, a few extra square metres creates much less additional value for a large park than for a small one. Changes in the value of natural capital of this kind, resulting from measures such as the destruction or creation of a park landscape, play a major part in the sustainability debate. Economists refer to this issue in terms of "marginal changes" or "marginal values".

In many cases a monetary value can be assigned to a certain category of an ecosystem service. A park that serves residents as a leisure facility, for example, has a very particular monetary value in the form of cost savings in the health system – i.e. a direct use value. It is considerably more difficult to determine the indirect use value of this park; its contribution to a better inner-city microclimate, for instance.

1.15 > The Hong Kong Park, opened in 1991, has direct benefits for citizens in the form of recreation, but also a high indirect use value because it improves the inner-city microclimate.

As a means of establishing the indirect use value of natural capital, an estimate can be made based on consumer surveys of how much a household would be willing to pay to improve environmental conditions – in this case, for example, for the enlargement of an inner-city park. Economists refer to this as "willingness to pay" (WTP). Another figure to be determined is the extent to which the population would accept compensation for any deterioration in environmental conditions (for example, if the park were reduced in size or built upon) – how great the "willingness to accept" (WTA) is.

WTP and WTA are often dependent on a cultural or societal context and are therefore impossible to determine in some cases. If a population attaches a cultural or even religious significance to a park, a landscape or a natural monument, it will be very reluctant to accept any changes to it, let alone its destruction. Many sustainability experts call for such factors to be taken into account in the valuation of natural capital, even if they are barely quantifiable.

Dearth of knowledge

How difficult it is to assess the value of natural capital is also demonstrated by a recent study conducted by German economists. The researchers analysed a range of publications on the theme of ocean acidification. They wanted to find out whether robust findings existed on the future costs of ocean acidification, and who might be affected by it.

Ocean acidification is, alongside global warming, one of the most feared consequences of climate change. The oceans absorb from the atmosphere a large proportion of the greenhouse gas carbon dioxide that is emitted by the burning of natural gas, petroleum and coal. Expressed in simple terms, this results in a build-up of carbonic acid in the water, and the pH value of the water gradually drops. Marine scientists fear that this could affect corals and fish larvae as well as bivalves and snails which produce calcareous shells.

The study found that publications on the economic impacts of ocean acidification largely deal with the direct

1.16 > The indigenous inhabitants of Australia, the Aborigines, believe that their continent is crisscrossed with invisible, mythical dreaming tracks – a special kind of cultural natural capital that was often fragmented or destroyed by construction schemes.

1.17 > In September 2009 fishers and other seafarers along the Pacific coast off Alaska protested against ocean acidification.

pH value
Chemists determine the acidity of a liquid with reference to the pH value. The lower the value, the more acidic the liquid. pH values range from 0 (very acidic) to 14 (very alkaline). Since the Industrial Revolution the pH value of the oceans has fallen from an average of 8.2 to 8.1. By the year 2100 the pH value could decrease by a further 0.3 to 0.4 units. That sounds negligibly small. But the scale of pH values is logarithmic. It is mathematically compressed, so to speak. In reality the ocean would then be 100 to 150 per cent more acidic than in the middle of the nineteenth century.

economic impacts on human beings, and particularly with the consequences for the fishing industry. Just a few papers analyse the situation with regard to coral reefs. While these mention that coral death could cause losses in tourism revenue, they stop short of any precise economic analysis. Moreover, not one publication mentions the indirect consequences of coral death; for instance, it would also have a detrimental effect on coastal protection. The authors of the study list a number of gaps in existing research content:

- A majority of the economic studies focus on direct economic impacts such as a decline in the catch of fish or shellfish in certain marine regions. Existence or bequest values are left out of the analysis.
- No knowledge is available as yet on how the pH value in coastal waters might change in the future. Hence it remains unclear which marine regions are likely to be most heavily affected. But precisely that knowledge is important in order to ascertain the magnitude of the economic consequences in situ – and to intervene with well-targeted counter-measures.

Another fundamental problem is that the findings on ocean acidification in scientific publications are often presented in a form that is not usable for an economic analysis. Often, simplifying assumptions are necessary in order to be able to project changes in the gross revenues of fishers from data on changes in a calcification rate in bivalves.

Accordingly, the authors come to the conclusion that it is simply not possible to assess the economic impacts of ocean acidification today because even just the marine biochemical processes are too complex. Furthermore, many published studies refer to organisms which are easy to observe or to keep in a laboratory but which have absolutely no claim to any particular economic relevance or vital importance to ocean food webs. Since the scientific journals are the basis for the economic studies, their credibility in turn must be considered very limited.

The authors of the study therefore propose closer cooperation between natural scientists and economists for the future, addressing not just ocean acidification but all other environmental threats and ecosystem services as well. In collaboration it would be possible to tackle natural sciences research topics which are also of economic significance. Perhaps in that context organisms might be selected for studies specifically because they are interesting from a market economic viewpoint.

Prioritized for protection: critical natural capital

The forms of natural capital of particular interest today are those which are so significant that everything possible should be done to prevent their destruction. Sustainability theorists refer to these as critical natural capital stocks. A majority of experts include in this category forms of natural capital which are not substitutable by anything else – for example, scarce groundwater resources in the arid zones of Africa. This critical natural capital must be preserved because it is of elementary importance for human beings.

Other experts say critical natural capital also includes natural areas which merit protection not because they are existentially important to people but because they are habitats for threatened plant and animal species. This somewhat broader view of critical natural capital is supported by nature conservationists in particular – among them, the British environment agency “Natural England” (“English Nature” until 2006). Back in the 1990s this agency defined several categories which can help to identify land-based critical natural capital:

- Small-scale habitats with rare or threatened organisms;
- Ecosystems that represent a characteristic habitat with all the typical plant and animal species;
- Areas that provide important services such as protection against erosion, absorption of environmental pollutants or provision of drinking water;
- Areas of geological significance, particularly geological formations like the Grand Canyon in the USA, which are of special scientific interest or unique character.

Sustainability theorists stress that critical natural capital is definitely not to be equated with pristine wilderness, for often it is actually natural capital cultivated by people and already in use. Hence, continued prudent use is already well established, they argue. Nevertheless, in many cases they would insist on the need to define precise threshold or limit values which must not be exceeded, as otherwise unacceptable losses of natural capital will occur.

Uniting to conserve natural capital

The good news is that over the years a number of large-scale initiatives have been successful in protecting different forms of critical natural capital. Noteworthy successes have been the establishment of national parks and the adoption of various international conventions or special directives on nature conservation. In these cases the urgency of the need for action was plain to see, making it unnecessary to determine the value of the natural capital in detail beforehand.

One example of these forward-thinking conservation efforts was the International Montréal Protocol of 1989, which prohibited the use of chemical substances that deplete the ozone layer. To this end, very concrete limit values for the production of chemicals were specified. The signatory countries made a commitment to reduce and ultimately completely phase out the emission of particular substances. In this way it was possible to conserve the ozone layer as a primary value and as natural capital of life-and-death importance.

A further example is the Washington Convention (Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES) which has strictly regulated trade in rare or endangered species since 1973.

Millennium Development Goals

In September 2000, heads of state and government from 189 countries gathered in New York for, at that time, the largest ever summit of the United Nations. They adopted the Millennium Declaration which sets out a four-point list of the most important political challenges for the twenty-first century:

- Peace, security and disarmament,
- Development and poverty eradication,
- Protection of the common environment,
- Human rights, democracy and good governance.

Taking these major challenges as a basis, a working group made up of representatives of the United Nations, the World Bank, the International Monetary Fund and the Organisation for Economic Co-operation and Development (OECD) derived the following eight Millennium Development Goals (MDGs):

- MDG 1: To eradicate extreme poverty and hunger;
- MDG 2: To achieve universal primary education;
- MDG 3: To promote gender equality and empower women;
- MDG 4: To reduce child mortality;
- MDG 5: To improve maternal health;
- MDG 6: To combat HIV/AIDS, malaria and other diseases;
- MDG 7: To ensure environmental sustainability (integrating sustainable development into country policies, protecting environmental resources, reducing biodiversity loss, enabling people to access safe drinking water);
- MDG 8: To develop a global partnership for development.

For each goal, specific subsidiary targets were defined and time-frames specified for achieving them. Some of these efforts were a resounding success; for instance, the target of halving, from 1990 to 2015, the number of people worldwide whose income is less than 1,25 US dollar per day. This target was actually achieved in 2010.

Other targets, however, proved impossible to implement. The reasons for this failure were many and varied. Some were simply too ambitious. In other cases, the practicalities of implementation on the ground rendered the goals and targets unattainable. The process itself was not without problems: critics have pointed out that development funding which the Group of Eight (G8) major industrialized nations had contributed to funds managed by the World Bank, the International Monetary Fund and the African Development Bank were often allocated to purposes for which it was not intended, despite originally being earmarked for activities in pursuit of the MDGs.

Common goals for a sustainable future

In the year 2000 a working group convened by the United Nations formulated eight Millennium Development Goals (MDGs) which were to be accomplished by the year 2015. These were intended to bring about clear improvements in the living situation of people in developing countries and emerging economies and, at the same time, to conserve various forms of natural capital. The MDGs undeniably focus on the reduction of poverty and poverty-related hardships, and on aspects like health and education.

Today it is evident that these goals have not yet been achieved worldwide. A further United Nations working group has therefore now defined Sustainable Development Goals (SDGs) for the period from 2015 to 2030 that frame objectives in more concrete terms than the MDGs did. The SDGs are no longer restricted to the developing countries but address the whole world. Moreover, by taking the domains of sustainable agriculture, energy and climate change and the oceans into account, they are designed to have a stronger focus on the conservation of natural capital. The following aspects are considered essential to the SDGs:

- Food security and sustainable agriculture,
- Water supply and improved hygiene,
- Energy,
- Education,
- Poverty reduction,
- Resources to conduct the SDG process,
- Health,
- Climate change,
- Environment and natural resource management,
- Employment.

These aspects are sorted by priority. Taken together, they illustrate clearly that the United Nations working group has endeavoured to give balanced consideration to all the aspects that make up the classic three-pillar model of sustainability. Developments over the coming years will show whether states actually succeed in striking this balance.

Conclusion

"Sustainability" – a difficult concept to define

For all its positive connotations, these days the concept of "sustainability" is so broadly conceived as to make it ill-defined and vacuous. Originally, "sustainability" meant something like: making only such use of natural, renewable resources that people can continue to rely on their yields in the long term. The concept was coined by Hans Carl von Carlowitz, chief mining official of the Principality of Saxony. Faced with massive deforestation caused by the demand for fuelwood for metal smelting, in 1713 he called for "continuously enduring and sustainable use" of the forest. But the concept only became a buzzword in the 1980s with the publication of the report by the World Commission on Environment and Development (WCED). In response to rising environmental degradation since the mid-1950s, the WCED defined several major sustainability goals which included reducing poverty, stimulating economic growth in developing countries and protecting the environment. However, the report lacked a clear model of how to achieve sustainability. To be sure, the "three pillars" model which envisions sustainability resting on the supports of the environment, economy and society was derived from the WCED report, but it also became apparent that these aspects are not treated as equal in status. Until now, economic interests have tended to be a higher priority than environmental protection.

An important precondition for sustainable development is that what is actually deemed worthy of protection must be clearly defined. In this context experts make use of the concept of natural capital. This comprises all stocks of natural assets, for example the soil or the ocean, which give rise to natural products and services such as fresh air or drinking water. How strictly these natural assets are to be protected is a matter on which there are still divergences of opinion. For instance, experts differentiate between strong and weak sustainability. According to the model of weak sustainability, forms of natural capital that have been consumed can in principle be replaced without limit by real capital and human capital. According to the idea of strong sustainability, in turn, forms of natural capital can only be consumed if they can be replaced by equivalent natural capital.

To determine the significance of different forms of natural capital more precisely, experts analyse which different types of ecosystem services they provide. These include aspects like the climate-regulating effect of the ocean, for example, as well as aspects that are not directly measurable like the beauty of a landscape. In many places natural capital is under threat or has already been destroyed by environmental degradation. However, the prevention of further damage or the restoration of previously damaged areas costs money. For that reason, various conservation measures are often weighed against each other in cost-benefit analyses. But while the costs can mostly be established easily, the benefits of many ecosystem services are quite difficult to quantify. In order to have some means of assessing the economic value of an ecosystem service nevertheless, experts have defined different value categories. Some of these arise from the use of natural capital and some from its mere existence. Hence natural capital also has an existence value, which arises from the sheer pleasure of knowing that certain creatures or habitats exist.

As a basic principle, scientists advise prioritizing the protection of both critical natural capital and ecosystem services, which means all those which are existentially important for humans – such as scarce groundwater resources in arid zones.