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A framework for the practical application of the concepts of critical natural capital and strong sustainability

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Abstract

This paper develops a methodology for identifying that natural capital—called critical natural capital (CNC)—the maintenance of which is essential for environmental sustainability. By consideration of the characteristics of natural capital, of the environmental functions that these characteristics enable natural capital to perform and of the importance of these functions to humans and the biosphere, it shows how sustainability standards in respect of these environmental functions may be derived. The difference between the current situation and these standards is termed the sustainability gap. The methodology that emerges from bringing these ideas together into a single analytical framework enables policy makers to identify the extent of current unsustainability, the principal causes of it, the elements and processes of natural capital (the CNC) which need to be maintained or restored to close the sustainability gap and the costs of so doing. The framework should therefore be of use in identifying priorities and policies for moving towards environmental sustainability.

Keywords: Critical natural capital; Environmental functions; Environmental sustainability; Sustainability gap

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1. Introduction

This paper was written as the framework paper of a European research project on critical natural capital (CRITINC). It seeks to develop a classification of critical natural capital and its functions so that the term 'environmental sustainability' can be more clearly defined in operational terms than is often currently the case. Such a classification would permit the empirical determination of the social and economic implications of giving priority to environmental sustainability in public policy making, by investigating how economic and social options are constrained if critical environmental functions are sustained. The first requirement in developing a classification of critical natural capital is to derive a clear conception of natural capital itself and this is the purpose of Section 2. Section 3 distinguishes between weak and strong sustainability in relation to natural capital. Section 4 digs deeper into the concept of natural capital, classifying its characteristics and functions and discussing the values to which they give rise. Section 5 brings together the ideas from Section 3 and Section 4 and sets out both principles of environmental sustainability and shows how environmental standards can be derived from them. The purpose of these standards is to provide as objective an indication as possible of whether environmental policy is moving human society towards environmental sustainability. To achieve this, the sustainability standards need to be as firmly grounded as possible in natural science, with assumptions and the elements of uncertainty clearly defined. Section 6 shows how the whole schema can be organised into a framework that is related to the economic system and the national accounts, and how various measures can be derived from it. It is intended to be a positive, rather than normative, framework for the identification of environmental sustainability and, therefore, of the critical natural capital that is responsible for the critical environmental functions, the maintenance of which is the definition of environmental sustainability used in Section 5. Section 7 concludes the paper with a discussion of the policy implications of the CRITINC framework.

2. The concept of natural capital and its functions

Capital is one of the core concepts of economics and there is no space in this paper to go into either the use of the concept itself in economic theory, or the genesis and evolution of the term 'natural capital'. Some illustrative references to the latter subject may be found in Jansson et al. (1994) and Faber et al. (1995) and to the accounting and valuation of natural capital in Lutz (1993) and Faucheux and O'Connor (1998).

The essence of the concept of capital is that it is a stock that possesses the capacity of giving rise to flows of goods and/or services. Classical economics identified three types of capital stock: land, labour and human-made capital (often just called 'capital'). Much neo-classical economics in its representation of production functions omitted land and only focused on labour and capital. With the increase in awareness of the role of environmental resources in production, some production functions have been extended to include energy and material inputs as well (see, e.g. Jorgenson and Wilcoxen, 1993). However, the treatment of energy and other environmental resources in a conventional production function may not be satisfactory because the range over which substitutions between factor inputs are physically meaningful may be quite small. As Smith and Krutilla (1979) note: 'The adjustments... by the factor substitutions represented in an abstract production function may well violate physical laws.' Moreover, they further note that treating natural resources as if they were conventional inputs 'is not necessarily valid for addressing the problem (of environmental scarcity) when it involves services of non-priced common property environmental resources also required in production and consumption processes.' (Smith and Krutilla, 1979, p. 29). Ekins (1992) has disaggregated the capital stock into four different types of capital: manufactured, human, social/organisational and natural (also called ecological or environmental) capital. Each of these stocks produces a flow of 'services', which serve as inputs into the productive process.

a) Manufactured capital comprises material goods—tools, machines, buildings, infrastructure—which contribute to the production process but do not become embodied in the output and, usually, are 'consumed' in a period of time longer than a year. Intermediate goods, in contrast, are either embodied in produced goods (e.g. metals, plastics, components) or are immediately consumed in the production process (e.g. fuels).

b) Human capital comprises all individuals' capacities for work; while social and organisational capital comprises the networks and organisations through which the contributions of individuals are mobilised and coordinated.

c) Ecological capital is a complex category which performs four distinct types of environmental functions (see below and cf Pearce and Turner, 1990), two of which are directly relevant to the production process. The first is the provision of resources for production, the raw materials that become food, fuels, metals, timber, etc. The second is the absorption of wastes from production, both from the production process and from the disposal of consumption goods. Where these wastes add to, or improve the stock of ecological capital (e.g. through recycling or fertilisation of soil by livestock), they can be regarded as investment in such capital. More frequently, where they destroy, pollute or erode, with consequent negative impacts on the ecological, human or manufactured capital stocks, then, as agents of environmental deterioration, they can be regarded as bringing about negative investment, depreciation or capital consumption. The third type of environmental function does not contribute directly to production, but in many ways is the most important type because it provides the basic context and conditions within which production is possible at all. It comprises basic life-support functions, such as those producing climate and ecosystem stability and shielding of ultraviolet radiation by the ozone layer. The fourth type of environmental function contributes to human welfare through what may be called 'amenity services', such as the beauty of wilderness and other natural areas. Both lifesupport functions and amenity services are produced directly by ecological capital independently of human activity, but human activity can certainly have an (often negative) effect on the responsible capital and therefore, on these functions produced by it. Wealth creation is the process of using the four types of capital in combination to give rise to flows of goods and services which people want, in such a way that the capital stocks and the non-monetary flows of services from natural capital, are maintained or enhanced in quantity or quality. If the capital stock is not maintained, then eventually the flow of goods and services to which it gives rise will decrease, i.e. any level of flow that is associated with a reduction in the capital stock is unsustainable. Put another way, a declining capital stock is an unambiguous indicator of unsustainability in the flow of goods and services that derive from it. Each type of capital stock may therefore be associated with a type of sustainability. For example, a declining natural capital stock (for evidence of this, see Vitousek et al., 1997) is a sign of environmental unsustainability. This raises the question as to whether different types of capital may act as substitutes for each other. Where they can, it is clear that sustainability may be consistent with the decline of one type of capital stock as long as another type of capital is increasing sufficiently to compensate for this decline. This issue is discussed in Section 3.

3. Distinguishing between weak and strong sustainability

If sustainability depends on the maintenance of the capital stock, then an important issue is whether it is the total stock of capital that must be maintained, with substitution allowed between various parts of it or whether certain components of capital, particularly natural capital, are non-substitutable, i.e. they contribute to welfare in a unique way that cannot be replicated by another capital component. Turner (1993), identifies four different kinds of sustainability, ranging from very weak, which assumes complete substitutability, to very strong, which assumes no substitutability so that all natural capital must be conserved.

Very strong sustainability has been called 'absurdly strong sustainability' (Daly, 1995) in order to dismiss it from practical consideration. Turner's more interesting intermediate categories are:

- Weak environmental sustainability, which derives from a perception that welfare is not normally dependent on a specific form of capital and can be maintained by substituting manufactured for natural capital, though with exceptions.
- Strong sustainability, which derives from a different perception that substitutability of manufactured for natural capital is seriously limited by such environmental characteristics as irreversibility, uncertainty and the existence of 'critical' components of natural capital, which make a unique contribution to welfare. An even greater importance is placed on natural capital by those who regard it in many instances as a complement to man-made capital (Daly, 1991).

The point at issue is which perception most validly describes reality. Resolving this point is an empirical matter. However, if weak sustainability is assumed a priori, it is impossible to show ex post whether the assumption was justified or not, for the following reason. The assumption underlying weak sustainability is that there is no essential difference between different forms of capital or between the kinds of welfare which they generate. This enables, theoretically at least, all types of capital and the services and welfare generated by them to be expressed in the same monetary unit (although see Faucheux et al. (1998) for a fundamental theoretical critique of the possibilities of such monetisation). In practice, there may be insuperable difficulties in performing the necessary monetisation and aggregation across the range of issues involved, but the theoretical position is clear and strenuous efforts are being made to make it operational. But the numbers that emerge from these efforts can only show whether or not weak sustainability has been achieved, i.e. whether overall welfare has been maintained. They cannot shed any light on the question as to whether the assumption of commensurable and substitutable capitals was justified in the first place. In assuming away any differences at the start, there is no way of establishing later on whether such differences were important.

The strong sustainability assumption does not suffer from this severe defect in scientific methodology. In keeping natural capital distinct from other kinds of capital, it can examine natural capital's particular contribution to welfare, distinguishing between its contribution to production (through resource-provision and waste-absorption) and its services that generate welfare directly. The examination may reveal that, in some cases, the welfare derived from natural capital is fully commensurable with other welfare from production, so that in these cases substitutability with other forms of productive capital exists and the weak sustainability condition of a non-declining aggregate capital stock is sufficient to maintain welfare. In other cases, the outcome of the examination may be different. The important point is that, starting from a strong sustainability assumption of non-substitutability in general, it is possible to shift to a weak sustainability position where that is shown to be appropriate. But starting from a weak sustainability assumption permits no such insights to enable exceptions to be identified. In terms of scientific methodology, strong sustainability is therefore to be greatly preferred as the a priori position. There are other theoretical reasons for choosing the strong sustainability assumption, in addition to the practical reason of the sheer difficulty of carrying out the necessary weak sustainability calculations for complex environmental effects. Victor (1991) notes that there is a recognition in economics going back to Marshall that manufactured capital is fundamentally different from environmental resources.

The former is human-made and reproducible in the quantities desired, the latter is the 'free gift of nature' and in many categories is in fixed or limited supply. The destruction of manufactured capital is very rarely irreversible (this would only occur if the human capital, or knowledge, that created the manufactured capital had also been lost), whereas irreversibility, with such effects as species extinction, climate change or even the combustion of fossil fuels, is common in the consumption of natural capital. Moreover, to the extent that manufactured capital requires natural capital for its production, it can never be a complete substitute for resources. Victor et al. (1998) identify the elements of natural capital that are essential for life as we know it as water, air, minerals, energy, space and genetic materials, to which might be added the stratospheric ozone layer and the relationships and interactions between these elements that sustain ecosystems and the biosphere. Some substitution of these essential elements by manufactured and human capital can be envisaged, but their wholesale substitutability, as assumed by weak sustainability, appears improbable, certainly with current knowledge and technologies. In fact, if the process of industrialisation is viewed as the application of human, social and manufactured capital to natural capital to transform it into more human and manufactured capital, then it is possible to view current environmental problems as evidence that such substitutability is not complete. If our current development is unsustainable, it is because it is depleting some critical, non-substitutable components of the capital base on which it depends.

'Critical natural capital' may then be defined as natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital.

4. Characteristics, functions, values and attributes of natural capital

4.1. Characteristics of natural capital

Natural capital is a metaphor to indicate the importance of elements of nature (e.g. minerals, ecosystems and ecosystem processes) to human society. Natural ecosystems are defined by a number of environmental characteristics that in turn determine the ecosystems' capacity to provide goods and services. These environmental characteristics are many-fold (e.g. De Groot (1992) lists 53, classified in nine groups), which can be related in turn to the three fundamental environmental media (air, water, land) and the life they support, through the habitats they sustain. The four media of Table 1 become the basis of the natural capital framework developed later in the paper.

4.2. Functions of natural capital

It is the characteristics of the ecosystems, or natural capital, which give rise to the flows emanating from this capital, which De Groot (1992) calls environmental functions, defined as 'the capacity of natural processes and components to provide goods and services that satisfy human needs (directly and/or indirectly)'. The 'goods' (e.g. resources) are usually provided by the ecosystem components (plants, animals, minerals, etc.); the 'services' (e.g. waste recycling) by the ecosystem processes (biogeochemical cycling). Environmental functions have been identified and classified in a number of different ways. De Groot et al. 2002 (see also Chiesura and De Groot, this issue) divides them into four categories:

1) **Regulation functions**: regulation of essential ecological processes and life support systems (bio-geochemical cycling, climate regulation, water purification, etc.);

2) **Production functions**: harvesting from natural ecosystems of, for example, food, raw materials and genetic resources;

3) **Habitat functions**: provision by natural ecosystems of refuge and reproduction-habitat to wild plants and animals and thereby contribution to the (in situ) conservation of biological and genetic diversity and evolutionary processes.

4) **Information functions**: provision of many possibilities for recreation and aesthetic enjoyment, cultural and historical information, artistic and spiritual inspiration, education and scientific research.

Table 1. Characteristics of natural capital

Media	Main characteristics detrmining functioning of the (eco)system
Air	Atmospheric properties & climatological processes (e.g. air quality, precipitation, temperature, wind)
Water	Hydrological processes & properties (e.g. water reservoirs, runoff, river discharge, groundwater table, water quality…)
Land	- Bedrock characteristics and geological processes (e.g. minerals, tectonics) - Geomorphological processes and properties (e.g. weathering, albedo) - Soil processes and properties (e.g. texture, fertility, biological activity)
Habitats	- Vegetation characteristics (e.g. structure, biomass, evapotranspiration) - Fauna and flora (e.g. species diversity, dynamics, nutritional value) - - Life-community properties (e.g. food-chain interactions, decomposition) - Conservation value/ integrative aspects (e.g. integrity, uniqueness)

Pearce and Turner (1990) have grouped environmental functions into source, sink and service functions. To these Noel and O'Connor (1998) have added the categories of scenery, site and life support functions. Other scholars have used the term ecosystem (or ecological) services to capture the same idea.

For example. Daily (1997) defines ecosystem services as 'the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life' and Barbier et al. (1994) define ecological services as 'ecological functions that support and protect the human activities of production and consumption, or affect overall well-being in some way, thus impacting on human welfare'.

Underlying these similar categorisations, an important basic distinction may be drawn between the 'functions of natural capital and the 'functions for' humans which it generates (see also O'Connor (1996, 2000) for development and discussion of this distinction). The 'functions of natural capital (which correspond to De Groot's regulation functions or the life support functions in the classifications above) are the basic processes and cycles in the internal functioning of natural systems, which are responsible for sustaining and maintaining the stability and resilience of ecosystems (Holling et al., 1995). The 'functions for' humans provide resources for, and absorb the wastes from, human activities, and provide human welfare in other ways.

Without the 'functions of natural capital, no other category of functions would be able to exist on a sustained and systematic basis. This implies that the economic and other welfare which derives from the 'functions for' humans is dependent on the 'functions of natural capital, irrespective of whether people want them, know about them, or perceive them or not. Humanity's primary dependence on the 'functions of natural capital reflects the fact that, however they may perceive themselves, humans are a part of, and not apart from, nature.

A significant, if still barely understood, role in the 'functions of natural capital is played by biological diversity (Baskin, 1997), both in running the key processes that support the flow of goods and services and in maintaining functions of natural capital resilient to change. Resilience is the capacity of an ecosystem to buffer disturbance and surprise and thereby conserve future options and opportunities (see Holling (1994) for a discussion of biodiversity and resilience in relation to human population growth). This role of biodiversity can be thought of as an insurance regulatory function of natural capital. Thus, the regulatory functions play a fundamental role of life-support, by regulating the processes involving natural capital and maintaining the integrity of ecosystems and the biosphere. The 'functions for' people, however they are categorised, all contribute directly in some way to human welfare. As noted above, some act as inputs to, or waste absorbers from, the economy, others help to maintain human health or contribute to other aspects of human welfare. If environmental functions (both the life support functions 'of natural capital and those that provide directly 'for' people) contribute to human welfare, then they have value.

4.3. Values and attributes of natural capital

De Groot (1992) has identified nine different types of values of environmental functions, grouped under the three dimensions of sustainable development:

- Ecological (conservation and existence values),
- Social (human health, personal, community and option values).
- Economic (consumptive, productive and employment values).

These values are a direct source of human welfare. Conservation value principally resides in the regulation life-support functions. Existence value reflects the welfare people derive from simply knowing that some environmental function, or part of nature, exists. Many environmental functions contribute directly or indirectly to human health. Many environmental functions, especially the habitat and information functions, contribute to community well-being. Option value derives from the concerns that people have to maintain environmental functions for possible use by future generations. The economic values of consumptive and productive use mainly derive from the source and sink environmental functions. Employment values derive also from the service environmental functions (e.g. the dependence of much tourism on unspoilt natural areas),
In similar vein, CAG and LUC (1997) (Box 5.1; pp. 26-27) have derived a list of 'environmental attributes or services' which are related in Table 2 to De Groot's environmental function classification and three value categories. What is striking is how many of the CAG and LUC attributes have economic value, especially relating to the information functions (which include aesthetic, recreation/ tourism, historic, cultural, artistic, scientific and educational information) (see also Chiesura and De Groot (this issue) for a discussion of this issue).

It is clear from this categorisation that the loss of these functions could have serious economic implications, which are all too often not taken into account. Fig \ brings together these different ways of conceptualising and classifying the functions, at tributes and values of natural capital. It may be interpreted as follows. There are social, economic, ethical and environ mental influences on the natural capital stock, the elements of which are matter, energy and ecosys terns, which include human-cultivated ecosystems (e.g. plantation forests, crops). These elements are caught up in natural processes which sustain the ecosystems and all life within them, which are collectively called the 'functions of natural capital' and which may also be described as regulation, habitat or life-support functions. They both sus tain ecosystems and give them resilience. The elements and functions of natural capital generate a range of environmental functions for people. These functions include those earlier classified as habitat, production and information functions, or as source, sink and service functions, with the latter split into life-support, scenery and site functions. In this case, the habitat and life- support functions are related to people rather than to ecosystems (although just as, in general, the functions for people depend on the functions of natural capital, so the habitat and life-support functions for people depend on the continuing operation of the habitat and life-support functions related to ecosystems). Both the functions of natural capital and the functions for people are contingent on spatial factors, so that analysis of them must pay attention to the relevant spatial scale.

Table 2.
Relationship between environmental attributes, values and function types, from different classifications

Environmental attributes (CAG and LUC, 1997)	**Environmental functions (De Groot et al, 2002)**	**Environmental values (De Groot, 1992)**
Health/ survival	Regulation / habitat	Ecological conservation; social health
biodiversity	habitat	Ecological conservation, existence
Appreciation of the environment	Information, habitat	Social (personal, option), economic
Sense of place	Information, habitat	Social (community, option), economic
Historical character	Information, habitat	Social (community, option), economic
education	information	Social (personal, community, option), economic
recreation	Information, habitat	Social (community, option), economic
Value to the local economy	Production, information	economic

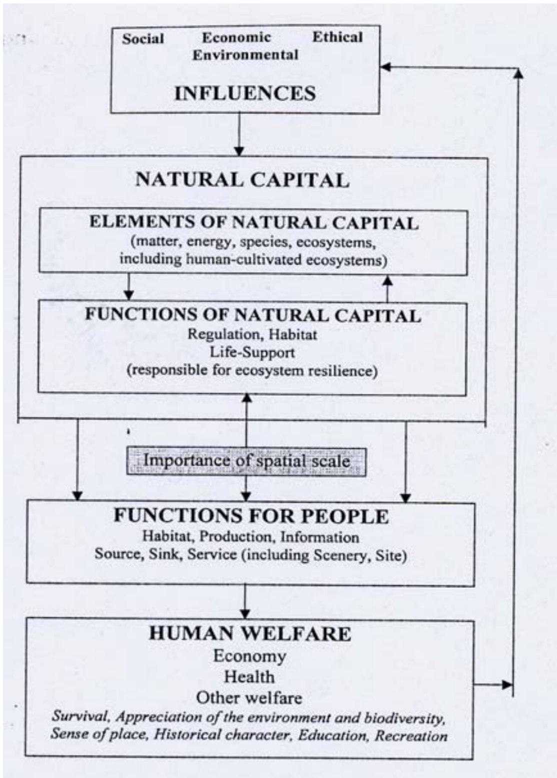

Fig. 1. Environmental functions and attributes: human influences and welfare.

The functions for people generate human welfare, here divided into three parts: economic welfare, health-elated welfare and all other welfare, including that associated with the attributes identified in Table 2 (here identified in italics). The core of the environmental problem is that in its use of environmental functions for people, particularly those which generate economic welfare, humanity is having a negative impact and influence on the natural capital stock, and particularly on the functions of this stock which are responsible for ecosystem stability and resilience. But in the long term, the welfare-generating 'functions for people' will only be sustained through the continued operation of the life-support 'functions of nature'.

The purpose of stressing in Fig. 1 the distinction between the fundamental 'functions of natural capital and the more obvious 'functions for' people is that the former are so often not perceived and therefore valued, by human society until the function is damaged or lost.
The identification of environmental functions and the natural capital that is required for them is largely an objective exercise informed by environmental science, although there remain large areas of uncertainty or even ignorance' concerning the causes, effects and dynamics of the 'functions of natural capital that sustain ecosystems. On the other hand, the perception and valuation of what the functions actually deliver to human life and society is a subjective matter. For those functions that contribute to the economy through market transactions, the conventions of market valuation may permit their value to be expressed in money terms and directly compared with other sources of economic value. For the functions that contribute to human health and wider human welfare and especially those that sustain ecosystems, the application of such conventions is problematic, both in theory and practice (see Faucheux et al., 1998).
Decision-making in these situations is likely to need other criteria and considerations. One of these may be the concept of environmental sustainability, which is the subject of the next section.

5. Definition and standards of environmental sustainability

5.1. Defining environmental sustainability

From a human point of view, what matters about the environment is not particular stocks of natural capital per se, but the ability of the capital stock as a whole to be able to continue to perform In this paper, the term 'risk' is applied to situations of known outcomes and probabilities, 'uncertainty' to situations where outcomes are known but not their probabilities, and 'ignorance' where even some outcomes may be unknown.
Hence, it is logical to define environmental sustainability as the maintenance of important environmental functions and therefore, the maintenance of the capacity of the capital stock to provide those functions. This is very much in line with the approach by English Nature (1994), which has defined environmental sustainability as follows: 'Environmental sustainability means maintaining the environment's natural qualities and characteristics and its capacity to fulfil its full range of functions, including the maintenance of biodiversity'.
Environmental functions are not necessarily uniquely performed by particular stocks of natural capital. It may be that, as discussed in Section 3, other types of capital may engender flows that are acceptable substitutes for some environmental functions. Nor need it be assumed that all environmental functions are so important for human welfare that they must be maintained. However, De Groot's four categories of environmental functions relate to very different aspects of the natural capital providing them, and therefore criteria for their importance, or criticality, and sustainable use need to be assessed in very different ways, bearing in mind also that each of the criteria needs to be interpreted in a way that reflects the essentially dynamic nature of ecosystems:

- for regulation functions (e.g. maintaining ecosystem resilience, waste recycling, erosion-prevention, maintenance of air-quality) criteria such as maximum carrying capacity, conservation of biodiversity, and integrity of essential life support processes are involved;
- for habitat functions (e.g. conservation of species) a spatial dimension is added (e.g. minimum critical ecosystem size);
- for production functions (e.g. resource-extraction) the maximum sustainable yield level is an important criterion;
- for information functions criteria are more driven by and derived from social science (e.g. perception of valuable landscapes; cultural and historic value, etc.).

In a situation of complete knowledge about the contribution of different functions to human welfare, their importance could be evaluated in these terms and the functions thereby deemed to be of high importance related back to the particular stocks of environmental capital which are responsible for them. Unfortunately, there is enormous uncertainty about which functions are important for human welfare and why, especially concerning those regulation and habitat functions which are believed to sustain life-processes, which compounds the difficulty of quantifying their contribution to human welfare. Although techniques of monetary valuation can capture some environmental values, both the techniques and the numbers they produce remain contested and fraught with problems of interpretation. Rather than using such techniques, it seems preferable to identify as 'important', or critical (and therefore essential for environmental sustainability), any environmental functions:

1) which cannot be substituted for, in terms of welfare generation, by any other function, whether environmental or not;
2) the loss of which would be irreversible;
3) the loss of which would risk, or actually entail, 'immoderate losses' (see below).

The simultaneous coincidence of uncertainty, irreversibility and possible large costs or immoderate losses, has long been recognised as an important consideration for environmental policy. The classic work of Ciriacy-Wantrup (1952) prefigured many of the current concerns of sustainability with his development of the concept of 'the safe minimum standard'. First Ciriacy-Wantrup (1952) identifies the existence of 'critical zones' for many, especially renewable, resources, where such a zone 'means a more or less clearly defined range of rates (of flow of the resource) below which a decrease in flow cannot be reversed economically under presently foreseeable conditions. Frequently such irreversibility is not only economic but also technological' (Ciriacy-Wantrup, 1952) and one may add with regard to extinct species, biological. In the terminology employed here, this means that the loss of environmental functions may be irreversible. The 'critical zone' concept is strikingly similar to that of the 'critical load' which is employed in modern environmental policy (for example, with regard to the reduction of SOz emissions mandated by the second sulphur protocol, see Ekins (2000), Chapter 10).

Then Ciriacy-Wantrup (1952) identifies the possibility of 'immoderate losses' arising from environmental degradation, ith respect to which:

'One important objective of conservation decisions is to avoid immoderate possible losses-although of small probability—by accepting the possibility of moderate ones—although the latter are more probable.' A decision rule that would achieve this is the 'minimax' criterion, which involves minimising maximum possible losses. The application of this criterion to resources characterised by critical zones leads Ciriacy-Wantrup (1952) (Chapter 18) to recommend the 'safe minimum standard' (SMS) as an objective of conservation (what today would be called environmental) policy: 'A safe minimum standard of conservation is achieved by avoiding the critical zone—that is, those physical conditions, brought about by human action, which would make it uneconomical to halt and reverse depletion.' In the context of complex systems, the critical zone can be thought of as the threshold, the passing of which may flip an ecosystem into another stability domain. Avoiding exceeding the threshold implies that management must build buffer capacity or resilience.

Bishop (1993) brings the SMS approach into the context of current environmental discourse by relating it to sustainability: 'To achieve sustainability policies should be considered that constrain the day to day operations of the economy in ways that enhance the natural resource endowments of future generations, but with an eye towards the economic implications of specific steps to implement such policies.' Here, the safe minimum standard has been converted into a sustainability standard. In the terms previously discussed, those activities that entail the possibility of irreversible effects and immoderate costs are now identified as environmentally unsustainable. The SMS approach suggests that policies that constrain or transform those activities towards sustainability should not be considered in a normal benefit-cost framework but one that seeks to avoid intolerable costs and to achieve the sustainability standard in a cost-effective way.

The claim of environmental sustainability to this pre-eminence as a policy objective is based on the importance of environmental functions for human welfare and because of the irreversibilities and large costs that may be associated with their loss. Even so, as noted above, not all environmental functions everywhere can, or need to, be sustained. Some assessment must be made of those functions that play a particularly important role in life support and human welfare, and policy for sustainability must be geared towards these. The more important the environmental function, the greater the weight that should be attached to its sustainable use. Important functions of this kind may be called 'critical environmental functions'. Where the stocks of capital which perform these functions cannot be substituted by other stocks of environmental or other capital which perform the same functions, they may be called 'critical natural capital' (CNC). With the present uncertain state of knowledge about ecosystems, and environmental functions generally, it is very difficult to judge which are critical and which are not. It is likely, for example, that all the regulation 'functions of natural capital are critical because it is not clear how natural systems would operate with impaired functions, although recent research suggests the existence of environmental thresholds and irreversible change when resilience is lost (Holling et al., 1995, 1996; Kates and dark, 1996; Carpenter, 2001; Scheffer et al., 2001). There is likely to be some, and perhaps considerable, ecological redundancy—not all species that occur in a given habitat and actually critical to the functioning of that habitat. However, it is not at all clear ex ante which species are, or might be, redundant. Science therefore suggests great caution in categorising environmental functions (and, by extension, elements of natural capital such as individual species) as 'non-critical' because of the danger that the loss of such functions may give rise to unsustainable effects.

However, in many cases, especially where the non-regulation functions are concerned, what counts as an 'unsustainable effect' rather than a sustainable economic cost is a matter of judgement which can only partially be resolved by science. Ethics and the attitude to risk also play a significant role here. It is important that the basis of judgement is articulated clearly, especially as to who is responsible for the effects and who is bearing their costs, and differentiating the contributions played by science, ethics and risk acceptance or aversion. If the key consideration for environmental sustainability is the maintenance of the functions that are important for human welfare, then in the first instance at least it is on the 'functions for people' on which attention should be focused. It was noted in the previous section that the principal contributions of these functions relate to the economy (with a further convenient division into source and sink functions), human health and other kinds of human welfare. It was also seen that the 'functions for people' are fundamentally dependent on the life-support 'functions of nature'.
This suggests that principles of environmental sustainability will need to maintain important environmental functions as follows:

- Source functions—the capacity to supply resources,
- Sink functions—the capacity to neutralise wastes, without incurring ecosystem change or damage,
- Life-support functions—the capacity to sustain ecosystem health and function and
- Other human health and welfare functions— the capacity to maintain human health and generate human welfare in other ways.

A number of principles of environmental sustainability have been put forward which relate to the generic environmental functions of resource supply, waste absorption and life support. For example, Daly (1991) has suggested four principles of sustainable development:

1) Limit the human scale (throughput) to that which is within the earth's carrying capacity.
2) Ensure that technological progress is efficiency-increasing rather than throughput-increasing.
3) For renewable resources, harvesting rates should not exceed regeneration rates (sustained yield); waste emissions should not exceed the assimilative capacities of the receiving environment.
4) Non-renewable resources should be exploited no faster than the rate of creation of renewable substitutes.

These principles are also among the rules that Turner (1993) has formulated 'for the sustainable utilisation of the capital stock', the others of which are: correction of market and intervention failures; steering of technical change not only to increase resource-using efficiency but also to promote renewable substitutes for non-renewable resources; taking a precautionary approach to the uncertainties involved.

Of these rules, the correction of failures, the nature of technological progress and the steering of technical change are more to do with achieving sustainability than defining principles for it; and in view of the complexity of applying the concept of carrying capacity to human activities, it seems desirable to express it more specifically in terms of those environmental problems that appear most pressing. Such considerations enable the Daly/ Turner rules to be reformulated into a set of seven sustainability principles which cover the four core categories of environmental functions and which are intended to ensure the maintenance of those that are critical, identified by the type of their contribution to human welfare:

1) Life support: anthropogenic destabilisation of global environmental processes, such as climate patterns or the ozone layer, must be prevented. Most important in this category are the maintenance of biodiversity (see below), the prevention of climate change by the stabilisation of the atmospheric concentration of greenhouse gases, and safeguarding the ozone layer by ceasing the emission of ozone-depleting substances.
2) Life support: critical ecosystems and ecological features must be absolutely protected to maintain biological diversity (especially of species and ecosystems). Criticality in this context comes from a recognition not only of the perhaps as yet unappreciated use value of individual species, but also of the fact that biodiversity underpins the productivity and resilience of ecosystems. Resilience, defined as 'the magnitude of the disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control its behaviour' (Foike et al., 1994) depends on the functional diversity of the system. This depends in turn, in complex ways, not just on the diversity of species but on their mix and population and the relations between the ecosystems that contain them. 'Biodiversity conservation, ecological sustainability and economic sustainability are inexorably linked; uncontrolled and irreversible biodiversity loss ruptures this link and puts the sustainability of our basic economic-environmental systems at risk.' (Barbier et al., 1994).
3) Source: the renewal of renewable resources must be fostered through the maintenance of soil fertility, hydrobiological cycles and necessary vegetative cover and the rigorous enforcement of sustainable harvesting. The latter implies basing harvesting rates on the most conservative estimates of stock levels, for such resources as fish; ensuring that replanting becomes an essential part of such activities as forestry; and using technologies for cultivation and harvest that do not degrade the relevant ecosystem and deplete neither the soil nor genetic

diversity;

4) Source: depletion of non-renewable resources should seek to balance the maintenance of a minimum life-expectancy of the resource with the development of substitutes for it. On reaching the minimum life-expectancy, its maintenance would mean that consumption of the resource would have to be matched by new discoveries of it. To help finance research for alternatives and the eventual transition to renewable substitutes, all depletion of non-renewable resources should entail a contribution to a capital fund. Designing for resource-efficiency and durability can ensure that the practice of repair, reconditioning, re-use and recycling (the 'four Rs') approach the limits of their environmental efficiency.

5) Life support/human health: emissions into air, soil and water must not exceed their critical load, that is the capability of the receiving media to disperse, absorb, neutralise and recycle them, without disturbing other functions, nor may they lead to life-damaging concentrations of toxins. Synergies between pollutants can make critical loads very much more difficult to determine. Such uncertainties should result in a precautionary approach in the adoption of safe minimum standards.

6) Other welfare: landscapes of special human or ecological significance, because of their rarity, aesthetic quality or cultural or spiritual associations, should be preserved.

7) All: risks of life-damaging events from human activity must be kept at very low levels. Technologies that threaten to cause serious and long-lasting damage to ecosystems or human health, at whatever level of risk, should be foregone.

As noted, of these seven sustainability principles, (3), (4) and, to some extent, (2) seek to sustain resource functions. Principle (5) seeks to sustain waste-absorption functions; (1) and (2) seek to sustain life-supporting environmental services and (6) other services of human value; and (7) acknowledges the dangers associated with environmental change and the threshold effects and irreversibilities mentioned above.

These relations between environmental functions and the sustainability principles are shown in Table 3 and related to environmental themes. The principles give clear guidance how to approach today's principal perceived environmental problems. They may need to be supplemented, as new environmental problems become apparent. At least some of the above sustainability principles seem to be winning international acceptance in that they are reflected in a number of international treaties, conventions and principles, including the Montreal Protocol to phase out ozone-depleting substances ((2) above), the Convention on International Trade in Endangered Species and the establishment of World Biosphere Reserves to maintain biodiversity ((3) above) and the Precautionary Principle, endorsed by the UN Conference on Environment and Development in Agenda 21, to limit environmental risk-taking ((1), (5) and (7) above). None of these international agreements was the outcome of detailed application of environmental evaluation techniques in a framework of cost-benefit analysis. They rest on a simple recognition that they represent the humane, moral and intelligent way for humans to proceed in order to maintain their conditions for life and are argued for on that basis.

Table 3. Sustainability principles related to environmental functions through environmental themes

Type of function	Sustainability principle (related to an environmental theme)
Sink	1. Prevent global warming, ozone depletion 5. Respect critical loads for ecosystems
Source	3. Renew renewable resources 4. use non-renewables prudently
Life support	2. Maintain biodiversity (especially species and ecosystems) 7. Apply the precautionary principle
Human health and welfare	5. Respect standards for human health 6. Conserve landscape/ amenity

The application of these sustainability principles permits critical environmental functions and the critical natural capital which performs them, to be tentatively (because of uncertainties) identified. In this identification, it is necessary to pay close attention to the space and scale over which the function is being performed. Given the interconnections between ecosystems, it is possible that what seems like quite a 'local' environmental function, is in fact dependent on environmental factors and processes that operate a considerable distance away, or are part of global or regional environmental systems. The application of these principles to environmental functions and the natural capital stock which gives rise to them enables critical natural capital (CNC) to be identified.

5.2. Deriving environmental sustainability standards

An important part of the identification and description of CNC is the derivation, on the basis of the above sustainability principles, of specific sustainability standards which define the minimum conditions for the CNC to perform its critical environmental functions. The standards may be expressed as indicators of the state of the CNC (e.g. quality of air or water, concentration of greenhouse gases) or of the pressure upon it (e.g. emissions into air or water). An enormous amount of work has now been carried out to define environmental indicators related to the key environmental themes. Table 4 gives one example of a set of these indicators, a matrix of the 'top 60' indicators related to ten policy fields, as identified by Scientific Advisory Groups convened by EUROSTAT.

It may be noted that, for the first five sustainability principles (related to sink, source and life-support functions and to pollution impacts on human health), biophysical standards can be derived largely through reference to natural science, invoking the seventh principle to cope with risk and uncertainty when necessary. Because of uncertainty, it is particularly difficult to define criticality in relation to biodiversity. In English Nature (1995a), the view is put forward that the stock of natural capital in the UK- should be maintained at a constant or increasing level. Only those elements that are replaceable should be lost and they should be recreated elsewhere. Those that are irreplaceable should be designated CNC and preserved. Four decision trees for the detailed identification of CNC are developed, in consideration of: (1) rare, threatened and declining species; (2) habitats and species assemblages; (3) environmental service provision; and (4) earth science (English Nature 1995a). A similar approach for the maritime environment is taken in English Nature (1995b), with the key issues on which the decision-trees are based being: (1) species reproduction; (2) species physical sensitivity; (3) island biogeography; (4) natural processes; (5) technological factors: ecological restoration (English Nature, 1995b).

The sixth sustainability principle is somewhat different from the others in that it deals with environmental functions that are exclusively concerned with human welfare, rather than the maintenance of ecosystems, and the value of which is more personal and subjective than the two source sustainability principles (3) and (4). With regard to such functions, CAG and LUC (1997) (Box 5.2) have listed a set of criteria for helping to determine the importance of their attributes: rarity, typicalness/representativeness, distinctiveness, quality, setting/context, historical continuity and recorded history, accessibility, ownership, popularity.

For some CNC the sustainability standards may already be being breached. In these cases, it is possible to identify a sustainability gap (SGAP) in physical terms, where SGAP is the physical difference between the current situation and the sustainability standards. This indicator is discussed further in Section 6.

6. A framework for the analysis of critical natural capital and strong sustainability

These ideas may be drawn together into a framework for the classification of CNC, as set out in Fig. 2, in which the upper rows of level 1 are the nine ecosystem characteristics listed earlier which give rise to the environmental functions emanating from natural capital, including cultivated natural capital. Below these ecosystem characteristics (and on the right of Fig. 2) are characteristics of the non-living human-made environment (e.g. landscape features, such as stone walls, or features of the built environment), which also give rise to environmental functions.

The functions emanating from these environmental characteristics are classified in four categories: source (the capacity to supply resources), sink (the capacity to neutralise wastes, without incurring ecosystem change or damage), life support (relating to ecosystem health and function) and functions for human health and welfare. Thus, the first three sets of functions are purely environmental in their formulation, while the fourth function category is specifically concerned with impacts on people. The matrices in level 1 show which characteristics give rise to which functions.

The entries in the matrices may be descriptive and/ or quantitative. They are likely to contain state indicators of the natural capital stock from which the relevant function emanates. The functions deriving from the non-living human-made environment are likely to be largely functions in the fourth category connected to history, culture, amenity and aesthetic appreciation.

Moving down to level 2, the sustainability concern (or theme) with regard to the source functions is depletion. It may be that particular state indicators from the level 1 matrices encapsulate the resource provision from particular functions (e.g. stocks of fish), in which case these indicators can be reproduced here to give a matrix of state indicators for the source functions. Similar matrices of state indicators may be produced for the sink (e.g. concentration of pollutant in a lake), life-support (e.g. species diversity in an ecosystem, landscape patchiness/mosaic, number of reserves or similar elements in the landscape that can provide ecological memory to disturbed areas, the number of corridors for birds, plants, wildlife, etc.) and human health and welfare (e.g. existence of human-made landscape features) functions.

Depletion is caused by economic activities of production and consumption. On the left of level 2 is a physical economic input-output (1-0) table. The rows of the 1-0 table are of depletable resources and, further down, of polluting emissions. The columns of the 1-0 table are of the usual economic sectors and final demand categories (including households). The resource rows show the inputs of the various resources into the different economic sectors and final demand, giving entries for the depletion of the source functions by particular economic activities and the totals then feed across to the source functions, to form Impact Matrix A. Depleting activities can also affect sink functions (Impact Matrix B). The classic example is the depletion of water resources. For example, reducing the water flow in a river can greatly reduce the river's ability to neutralise pollution. Depleting activities can also have an impact on life-support functions (where, for example, it reduces biodiversity) and human health and welfare functions (e.g. where water abstraction dries up rivers, or construction projects destroy valuable landscapes) and these are represented in the Impact Matrices C and D (see Ekins and Simon (this issue), for more detailed discussion of the application of the CRITINC Framework to water).

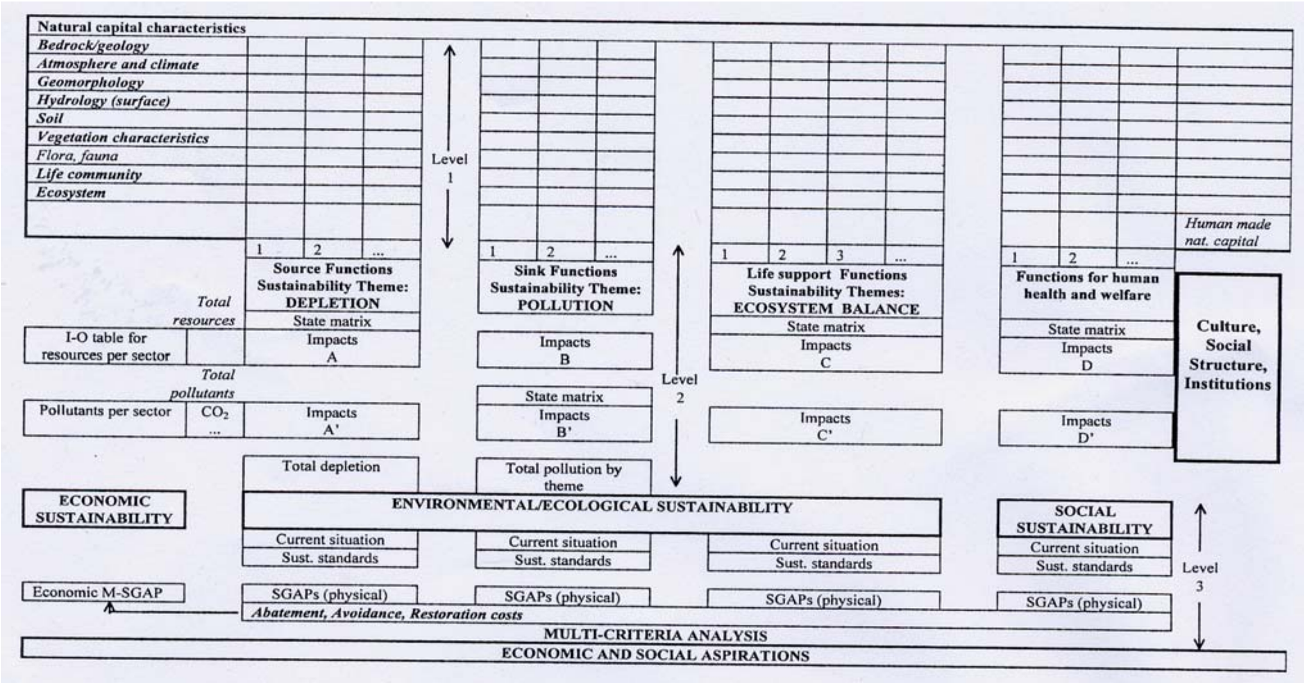

Fig. 2. Overall view of the CRITINC framework.

The relationship of the economic accounts to environmental flows in this way was advocated by the UN Statistical Office in 1993 (UN, 1993), since when there has been considerable development of physical 1-0 tables (PIOT) to match the monetary 1-0 tables which are a standard feature of national economic accounting. Thus, Vaze (1998) presents environmental 1-0 tables for the UK, in which emissions are disaggregated by economic sector and presented very much as shown in the left-hand section Fig. 2. The German PIOT described by Stahmer et al. (1990) constructs a full materials flow for the German economy. The sector' matrix, where the rows are different pollutants and the columns are the economic resource flows (measured in tonnes) appear be neath the usual economic rows of the monetary I -0 tables and feed across through into the eco nomic sectors as in Fig. 2. Pedersen (1994) shows how in a similar statistical structure for Denmark the inputs of 25 different types of energy into 117 different production sectors, with the resulting air emissions, can be shown. Fig. 2 is therefore very much a development of, rather than a departure from, current environmental-economic account ing practice, in which these physical flows are related not only to the economic sectors from which they derive, but also to the environmental functions on which they impact. In addition to causing depletion of resources and their resulting impact on environmental functions, economic activities also emit pollutants and these are shown in Fig. 2 in the 'Pollutants per sectors feeding down from those of the 1-0 table.

At the right of the 'Pollutants per sector' matrix is a column totalling all the different pollutants (including net exports and imports of pollutants). The different pollutants that are the rows of the 'Pollutants per sector' matrix then feed across to the different environmental functions. They may have an impact on the source functions (e.g. acid pollution may kill trees, water pollution may kill fish) and these impacts are recorded in Impact Matrix A\ The total depletion of source functions, recorded below Impact Matrix A', is therefore made up of the depletion recorded in both matrices A and A'. The pollutants will be received by different environmental media and this is recorded in Impact Matrix B', as per the sink functions.

The columns of pollutants in this matrix, appropriately weighted, will add to give the total pollutants per environmental theme. The pollutants may also have an impact on life-support functions (e.g. carbon dioxide on climate regulation) and these are recorded in Impact Matrix C'. Pollution may also have impacts on human health and welfare functions (e.g. air quality and respiratory disorders, making places unsuitable for recreation or reducing visibility of landscapes). These impacts are recorded in Impact Matrix D'.

So far the information system described has simply recorded the impacts of activities of depletion and pollution on different environmental functions. Level 3 of Fig. 2 introduces the concept of sustainability.

As noted at the start of this paper, sustainability with reference to human situations is widely recognised to have economic and social, as well as environmental dimensions. However, the focus of this paper is environmental sustainability and the economic and social dimensions of sustainability are only considered where they are affected by the use of natural capital. Thus, economic sustainability, on the left of Fig. 2, is only relevant here insofar as it is affected by the negative impact of human activities on environmental functions.

Similarly, on the right of Fig. 2, social sustainability is only relevant here insofar as it is affected by the negative impact of human activities on environmental functions for human health and welfare (e.g. the loss of recreation opportunities in the natural environment may lead to vandalism or other anti-social behaviour).

In line with the principles of environmental sustainability laid out earlier, it is possible to derive sustainability standards for the use of the source and sink functions and sometimes for the life-support and human health and welfare functions. Some of these standards will be locally specific (e.g. critical loads of particular ecosystems); some will be framed in national terms (e.g. air quality standards for human health); some may be related to global impacts (e.g. carbon emissions consistent with climate stability). These standards may be expressed in terms of state or pressure indicators, where the former shows the minimum threshold of the natural capital stock that is necessary for the function to be maintained and the latter shows the maximum pressure that the natural capital stock can withstand, while maintaining the function.

The difference between the current situation, the state of the natural capital stock or the pressure being put upon it and the sustainability standard, may be described as the 'sustainability gap' (SGAP) for that function. SGAPs will be expressed in physical terms and may be interpreted as the physical 'distance' to environmental sustainability in relation to the present situation and practices. It is these physical 'distances' that indicate that critical natural capital (CNC) is being depleted. The purpose of the framework of Fig. 2 is to enable the actual stock of CNC that is being depleted to be identified, by tracing back the functions to the environmental characteristics from which they derive. The framework also permits the depleting activity to be identified so that policy can be targeted where desired.

Assuming that SGAP does not represent an irreversible effect, it will be possible through abatement or avoidance activities (for environmental pressures) or restoration activities (for environmental states) to reduce the SGAP such that the sustainability standard is achieved. These activities may have a cost. For every (non-irreversible) SGAP, therefore, there will in principle be a sum of money corresponding to the least cost, using currently available technologies, of reducing the physical SGAP to zero. This cost, for each function, may be termed the monetary SGAP or M-SGAP. The purpose of such indicators would be to suggest targets for public policy, the achievement of which would indicate a situation consistent with environmental sustainability and to indicate the costs of that achievement, on the basis of current technologies, which is clearly of interest for policy making.

Because the M-SGAPs for different functions are all expressed in the same unit, they can be aggregated to compute an overall Gross SGAP or G-SGAP, for the economy as a whole. This may be used to indicate the economic 'distance' to environmental sustainability in relation to the present situation and practices. It may be noted that G-SGAP will decrease either as the environment improves (reducing the 'physical' sustainability gap) or as technologies of abatement, avoidance or restoration become cheaper. Expressed as a ratio, G-SGAP/GDP may indicate the 'intensity of environmental unsustainability', comparable to the widely used energy intensity calculation. This would enable the overall environmental impacts of different economies to be compared.

Where environmental policy reduces the SGAP, the environment will change, providing new information for policy making in the next period. Inter-temporal comparisons of the SGAP indicators between periods will give insights into how the categories in the four different categories are related to each other (see Ekins and Simon, 1998, 1999, 2001 for further discussion of the thinking behind the SGAP concept and details as to how the indicator may be derived).

For some of the life-support (e.g. in relation to the population of a certain species in an ecosystem or to the incidence of human diseases) and human health and welfare (e.g. in relation to the preservation of landscape or the existence of opportunities for environmental recreation) functions it may be impossible to identify a 'sustainability standard'. It may be that, for some of these functions, their loss would represent a sustainable economic cost (meaning that it represents a loss of welfare, which was presumably outweighed by the benefits of the activity which caused it), rather than an indication of unsustainability (which would be the case if the losses were irreversible and ran a risk of immoderate losses in the future). Instead of sustainability standards, for these functions Fig. 2 would record trends (e.g. trends in health or sickness). A negative trend would give cause for concern and if continued long enough might be considered to lead to an unsustainable situation, without any particular threshold of unsustainability being identifiable.

7. Environmental policy implications and conclusions

It is sometimes argued that, because of the potentially very great implications for human welfare of environmental unsustainability, achieving environmental sustainability should be the key goal of environmental policy. The purpose of identifying and inventorying CNC, through the derivation of sustainability standards and the identification of sustainability gaps, is to give guidance as to whether environmental policy is in fact moving human impacts on the environment towards environmental sustainability or not. To achieve this purpose, the sustainability standards need to be as firmly grounded as possible in natural science, with assumptions and the elements of uncertainty clearly defined.

Fig. 2 seeks to give a positive, rather than a normative, framework for the identification of environmental sustainability and, therefore, of the critical natural capital which is responsible for the critical environmental functions, the maintenance of which is the definition of environmental sustainability. But however clearly sustainability standards can be defined and, whatever level of technical consensus they can obtain, it will remain a fundamentally political choice as to how much priority to accord environmental sustainability as a political goal and how fast to seek to move towards it. There is no presumption in Fig. 2 that environmental sustainability is the predominant goal of public policy. The pressures and demands on public policy are many and it is easy to conceive of situations in which policy makers would trade off environmental sustainability in order to achieve other social and economic aspirations. It is not the purpose of this methodology to argue for environmental sustainability as a major goal of public policy. It is to try to derive an understanding of environmental sustainability and a way of making it operational through defined standards and indicators, so that judgements can be made as to whether human societies are moving towards environmental sustainability or not. Where governments have a commitment to achieving sustainability, then increasingly, policy targets will move closer and closer over time towards sustainability standards. Where the targets and standards coincide, they may be called sustainability targets. It is important for society to be able to identify such trends on a widely agreed basis. It is equally important for it to be able to identify trends that are moving away from environmental sustainability and to give insights into the possible implications of this for human welfare. Thus, the purpose of the framework outlined in Fig. 2 is to make transparent the trade-off between environmental sustainability and other goals when it occurs. It seems to be desirable that, when policy makers do decide to trade off the future for the present, this situation is recognised and debated in its true terms. The information system outlined in Fig. 2 would enable this to be the case.

As a complete information system that covers all the environmental themes that are of concern with regard to environmental sustainability, the framework of Fig. 2 would give a comprehensive overview of environmental sustainability comparable to the treatment of the national economy in the system of national accounts. However, it is not necessary for the information system to be comprehensively realised before it can be useful. It can also be used for analysis of projects or in relation to particular environmental functions that may be under threat.

It has been shown that natural capital may be under threat from a number of factors, which may be social, cultural, economic or ethical in nature. In seeking to sustain CNC, it is necessary to identify which activities, customs or attitudes are having, or might have, a negative impact on CNC and then devise ways of easing these pressures. The ways chosen are likely to have social and economic implications and may involve costs. These implications may be explored through the following procedure:

1) Identification of the function(s) under threat or investigation, and their placement in the relevant category (source, sink, life-support or human health and welfare),
2) Relation of the functions back to the natural capital from which they emanate,
3) Preparation of the various impact matrices (A-D, A' D'),
4) Derivation of sustainability standards for the functions, if possible, or trends in those cases where sustainability standards cannot be identified,
5) Where standards have been identified, calculation of the SGAPs in relation to them,
6) Description of the economic or social aspiration that is putting the function under threat or pressure, in terms of the benefit that its realisation would yield. Investigation of alternative ways of partially or wholly achieving the aspiration,
7) Application of a system of decision-analysis, such as multi-criteria analysis, which might or might not seek to weigh the different impacts on a common scale, to give insights into the implications of applying the strong sustainability principle (i.e. maintaining those environmental functions identified as critical by ensuring that, at worst, the SGAPs did not increase) and into the various trade-offs that could be made short of applying this principle.

   It would be clear from this analysis to what extent, if the strong sustainability principle was not being applied, the future was being traded off for the sake of the present.

This procedure should generate insights into what is likely to be entailed for society as a whole if the strong sustainability principle, which mandates the maintenance of CNC at least at today's levels and in some cases may require its restoration to higher levels (where possible), were to be applied through environmental policy in a number of important environmental areas. From such analysis, tentative conclusions might be able to be drawn concerning the social and economic implications of the general application of the strong sustainability principle.

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