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Identifying critical natural capital
Conclusions about critical natural capital

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Abstract

This paper summarises the main results of the CRITINC project and briefly describes the case studies in which the CRITINC methodology was applied. These related to air quality, river systems, forests, urban areas, coastal wetlands and agricultural and water resources. The paper concludes that the methodology provides a way of systematically considering different uses of and impacts on the environment, with a view to evaluating whether environmental functions are being used sustainably and the extent of any sustainability gap, identifying the source of environmental pressures, and monitoring whether policies aimed at environmental improvement are being effective.

Keywords: Enviromental functions; Environmental sustainability; Critical natural capital (CNC); CRITINC methodology

1. Theoretical insights from the CRITINC project

The common theoretical approach underpinning the CRITINC papers is that the environment as natural capital may be conceptualised as contributing to human life and activity through the performance of environmental functions (Hueting, 1980). As human populations and activities have increased, so have the demands on these functions, such that the demands on them cannot now all be fulfilled; there is competition between functions. The continuing over-use of some functions may result in other functions being lost. This may have serious implications for the ability of the environment to sustain human lives and activities in the future.

As its starting point, CRITINC adopted a definition of environmental sustainability as the maintenance of important environmental functions. Critical natural capital (CNC) is the natural capital which enables such functions to be performed, with the additional condition that, for any particular CNC, and resulting environmental function, there is no substitute type of capital, natural or human-made, which would enable the same function to be performed to the same extent, i.e. the CNC is non-substitutable in respect of the function in question. The strong sustainability principle holds that CNC should be absolutely protected.

Two major general conclusions are worth emphasising as among the most important insights from the CRITINC project. The first is that it is

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not possible to identify CNC as particular elements of natural capital. The complexity of natural systems is such that environmental functions may be enabled or performed by processes resulting from the interactions between elements of natural capital as much as from the elements themselves. These interactions derive from certain characteristics of the natural capital stock, and it is the characteristics that need to be safeguarded if the functions are to be maintained. Thus it is important always to consider functions in relation to the interacting characteristics of natural capital as well as to the natural capital itself.

The second conclusion concerns the nature of the environmental functions themselves. These were classified into four groups:

- Source (So) functions: those which provide resources for human activities.
- Sink (Si) functions: those which absorb, neutralise and recycle wastes from human activities.
- Life Support (LS) functions: those which act to maintain ecosystems.
- Human Health and Welfare (HW) functions: those, which contribute directly to human health and welfare.

Behind this classification there is a more fundamental distinction between environmental functions which needs to be emphasised, a distinction drawn in the CRITINC project between 'functions for' and 'functions of'.

The 'functions for' are those environmental functions which provide direct benefits for humans, whether resources for the economy (So), waste-processing services (Si) or health and amenity services (HW). These are the functions which are generally most easily perceived and appreciated, and towards the maintenance of which most environmental policy is directed.

The 'functions of' the environment are those which maintain the basic integrity of natural systems in general and ecosystems in particular. These functions are not easily perceived, and scientific knowledge about them is still uncertain and incomplete. What may be said with certainty, however, is that whether science understands these functions or not, and whether people value or are ignorant about them or not, the continued operation of the 'functions of' the environment is a prerequisite for the continued performance of many of the 'functions for' humans. Looked at in isolation, these 'functions of' the environment may appear useless in human terms, and therefore, dispensable. Considered as part of a complex natural system, these functions may be essential for the continued operation of other functions of much more obvious importance to humans. The danger is that the isolated view, or scientific ignorance about the natural complexity, may result in 'functions of' being sacrificed for economic or social benefits, without appreciation of the wider implications.

The situation is made more complex still by the fact that there is clearly an impact from the performance of the 'functions for', especially when they are enhanced by human intervention, on the 'functions of'. Thus increases in agricultural productivity, for example through intensification, may have seriously negative effects on the functions of ecosystems, as may the disposal of wastes above ecosystems' critical loads. Scientific uncertainty about these effects, and about thresholds of resilience for the 'functions of', argues for caution over activities which may threaten them. Given that this resilience seems most likely to be related to biodiversity, the continuing loss of biodiversity, globally and in Europe, is a major cause for concern.

Returning to the definition of environmental sustainability given earlier, clearly the major factor in its operationalisation is the process for identifying environmental functions as 'important'. The conventional economic approach to such a process is to assign a monetary value to the benefit accruing from the function, which should then be maintained unless a larger monetary value would accrue from an activity, which resulted in its necessary destruction. It may be noted in passing that the consistent application of even this conventional economic approach would result in far less environmental degradation than at present, because so much environmental damage is still given no value at all.

However, there are many well known problems in seeking to give monetary valuations to complex environmental functions, as was discussed in some of the papers and has been extensively explored elsewhere (see, for example, Foster, 1997), and this was not the approach adopted by the CRITINC project, which sought instead to define the importance of environmental functions in more fundamental ways, based on the following criteria:

- Maintenance of human health: functions should be maintained at a level to avoid negative effects on human health. These effects may be physical or psychological, resulting from the loss of environmental quality or amenity.
- Avoidance of threat: functions should be maintained if there is any possibility that their loss would entail unpredictably large costs. This criterion is even stronger if there is any risk that the loss of the function would be irreversible. It is most obviously applicable to considerations of biodiversity and the maintenance of ecosystem integrity.
- Economic sustainability: functions that provide resources for, or services to, economic activities should be used on a sustainable basis (i.e. one that can be projected to continue into the long-term future).

On the basis of these three broad criteria, which establish in general terms whether an environmental function should be considered important or not, a number of principles of environmental sustainability may be derived, related to current environmental issues of concern. The principles derive from the perception that, in order for the environment to be able to continue to perform its functions, the impacts of human activities on it must be limited in some ways:

1) At the global level it would seem important not to disrupt the climate,
2) Deplete the ozone layer,
3) Significantly reduce biodiversity.
4) For pollution generally, emissions should not exceed levels at which they cause damage to human health, or the critical loads of receiving ecosystems.
5) Renewable resources should be renewed, and the development of renewable substitutes should accompany the depletion of non-renewable resources.
6) Given the great uncertainty attached to many environmental impacts, and the possibility that some of these may give rise to very large costs, the precautionary principle should also be used as a sustainability principle, to limit environmental risks.
7) Precious landscapes and elements of the human-made environment should be preserved.

The first five of the above principles are fairly straightforward conceptually, and quantitative standards describing the environmental states (e.g. concentrations of pollutants) and pressures (e.g. emissions of pollutants) that are consistent with them may be readily derived (though not without a broad range of uncertainty in some cases) from environmental science.

The sixth principle, a statement of adherence to the precautionary principle, acknowledges that an environmentally sustainable society will choose to forgo even quite large benefits rather than run even a very small risk of incurring potentially catastrophic costs in the future. Environmental science is, again, the best source of insight into the existence of such risks. Despite the precautionary principle appearing as principle 15 in the Rio Declaration from the Earth Summit in 1992, there is little current evidence that societies are actually prepared to put it into practice.

The seventh principle is rooted entirely in aesthetic and cultural considerations, which are outside the realm of environmental science. It is not, therefore, possible to specify in general terms which landscapes should, or should not, be conserved. On the other hand, it is also not possible to conceive, in the contemporary context, of an environmentally sustainable society, which makes no attempt to identity outstanding landscapes or to conserve the ones that had been identified. Most countries have now enacted landscape designations of various kinds, internationally, nationally and at sub-national levels. Standards under this principle would assess the extent of these designations, and the rigour with which they were observed.

The above criteria and principles are put forward as the most basic requirements for environmental sustainability. There are good reasons why environmental sustainability should be an important objective of public policy. Some would say it should be a pre-eminent objective of public policy. Others will argue that there are situations in which human societies can, and perhaps should, compromise the health of their members and put at risk their economic future, and even their long-term survival, in order to achieve pressing present policy objectives. Sustainability has no automatic trump over these other objectives. It must be argued for on its merits, like them. It seems desirable, however, that, where environmental sustainability is being compromised, human societies are aware of the fact. It was an objective of the CRITINC project to provide a sound basis for such judgements and answers.

2. Application of the CRITINC framework

As noted in the Introduction to this special issue, each institute participating in the CRITINC project undertook a case study of a particular environmental issue in the context of the analytical framework that had been developed (see Figure 2 in Ekins et al. this issue). The major insights from the case studies now briefly follow. They are presented more extensively on the CRITINC website[1].

2.1. *Italy: air quality*[2]

2.1.1. *Natural capital characteristics and functions*

As one of the fundamental environmental media, air performs source, sink, life support and human health functions. While the source function (provision of oxygen and carbon dioxide to living organisms) is not currently affected by human activities, anthropogenic pollution of the air (i.e. over-use of the air's sink function) is having a negative effect on all the other categories of functions. These effects are due to alteration of the characteristics of the air, which produce climate and weather, and which control solar radiation input; and to changing the chemical composition of the air in the lower atmosphere, and increasing the concentration of atmospheric smoke and dust, with effects on humans, other living organisms, and on buildings. It is on the effects of air pollution on human health, with special reference to air quality in Milan, that this case study is focused. As noted earlier the maintenance of environmental functions related to human health is one of the basic criteria for environmental sustainability, so that air qualifies as CNC in respect of its functions that contribute to this.

2.1.2. *Sectoral pressures*

The case study identifies road transport as the principal sectoral pressure on the environmental functions of air which are related to human health, with significant contributions also coming from power generation, heating systems and industry, and, for (non-methane) volatile organic compounds (VOCs), solvents. For Milan, the great majority of health affecting air pollution comes from emissions of nitrogen oxides (NOx), carbon monoxide (CO), particulates and VOCs from road transport. The picture is similar in other major cities of the European union.

The effects of air pollution on human health are relatively well understood scientifically, and the World Health Organisation (WHO) has prescribed standards at which human health effects are kept at a very low (and implicitly acceptable) level. These standards may, on the basis of current knowledge, be considered sustainability standards, in the terms of the CRITINC framework. Italian national standards broadly follow the WHO standards, although there are a few cases where they are less stringent. Standards in other EU countries are also very much the same, as might be expected, although there are significant differences in the extent to which they are complied with.

[1] http://www.keele.ac.uk/depts/spire/Working%20Papers/CRITINC/CRITINC%20Working%20Papers.htm.

[2] Summarising 'Air quality in Milan: a case study for protecting critical natural capital in Italy' by Paola Doria, Davide Migliavacca, Davide Pettenella and Roberto Roson (Fondazione ENI Enrico Mattei).

Air quality in Milan has improved markedly since the late 1980s, when the standards for sulphur dioxide (SO_2), NOx, particulates, CO and low-level ozone were significantly exceeded. By 1997–1998 only the standards for NOx, CO and ozone were being exceeded, with the exceedances much reduced for NOx and CO. Only ozone had increased its exceedances over the level in 1990.

The Milanese experience of this kind of air pollution is largely replicated, with minor variations, in cities across the European union. Despite the overall improvement, 115 larger European cities still experience exceedance of the WHO air quality guidelines for at least one pollutant every year, with concentrations of NOx, CO, VOCs and ozone remaining relatively high in most cities. Pollution from particulates possibly causes 40 000–150 000 adult deaths per year in EU cities. (EEA, 1999).

2.1.3. Socio-economic implications of policies for sustainability

Despite the ongoing improvements, the case study considers that the situation in Milan remains unsatisfactory, both because of continuing exceedances, and because increases in traffic and changed weather conditions could increase those exceedances in the future. The case study, therefore, analyses the economic costs of achieving greater cuts in polluting vehicle emissions, as the principal contributor to Milan's air pollution problems.

Both technological and socio-economic (essentially traffic reduction) options for emission reduction are identified, and the costs of the options estimated. A model then computes which options would be the cost-effective means of achieving different levels of cuts in emissions.

The model results indicate that technological options by themselves, rather than forced behaviour changes, are the cost-effective means of achieving emissions reductions of up to 80%, with traffic reduction measures only being required if 90% emission cuts are to be achieved. Current exceedances of air quality standards in Milan suggest that 50% cuts in emissions would be sufficient to achieve compliance with the standards across all relevant emissions. The model suggests that emission cuts of this level could be achieved at negative net cost, even in the short term. Clearly these results depend on the model specification and assumptions, which have, however, been chosen on the best available current knowledge, though there is obviously some uncertainty.

Again, the Milanese situation would appear representative of that in the EU as a whole. Notwithstanding forecast traffic growth, air quality is expected to improve throughout the EU, such that by 2010 the average exposure of EU residents to air pollution concentrations is expected to decrease to half the level in 1990. As with the Milan case study, technology improvements, such as those contained in the European commission's Auto Oil programme, are envisaged to play the major role in emissions reduction (EEA, 1999). However, the costs associated with these emissions reduction are currently calculated to be substantial, which differs from the case study finding of large available cuts at negative net cost. Research on the reasons for this difference would seem desirable.

2.2. UK: river systems of conservation interest[3]

2.2.1. Natural capital characteristics and functions

River systems are fundamental elements of natural capital, performing a range of important environmental functions in all four of the CRITINC categories (source, sink, ecosystem performance, human health and welfare). This case study focused on two very different river systems in the West Midlands region of the UK:

- River Blythe: this is a river of high nature conservation interest, with a number of features of scientific importance, which make it a classic lowland river with high botanical diversity. The

[3] Summarising 'Rethinking Conservation: the use of multi-criteria appraisal methodology in river conservation' by Sandrine Simon (Open University).

river is classified as a site of special scientific interest (SSSI). The water quality improved substantially over the 1990s, and is now well towards the upper end of the UK's river quality classification. This enables water from the river to be abstracted for the public water supply (drinking, household water), and it is also abstracted for agriculture. The high water quality also enables a good population of fish to be supported, so that angling is a widespread and popular leisure pursuit. Otherwise nature conservation appears to have taken precedence over other leisure and amenity uses of the river. The river occupies a relatively narrow strip of green-belt land between two large and densely populated urban areas.
- River Trent (Stoke-on-Trent area): this is a major English waterway through a region that had a long industrial history. Although for much of its length it flows through pasture and farmland, the stretch reviewed in this case study flows largely through a built-up area and has been very polluted for many years. This has meant that water from the river cannot be used for the public water supply, it supports no fish and very little of botanical interest, and is little used for amenity and recreation. In fact, it came to be regarded as an open sewer, and was widely used by the public as a rubbish tip. Such usage affected the river's ability to support wildlife and recreational activities for a significant distance downstream.

However, over the last 30 years pollution control measures have begun to improve the water quality so that wildlife is beginning to return to downstream stretches of the river closer to the city. Moreover, water scarcity in the region is creating pressures for further improvements in quality, so that the water may be abstracted for the public water supply.

2.2.2. Sectoral pressures

The environmental functions of both the subject rivers of this case study are under continuing pressure from a variety of sources, although the pressures are very different in each case:

2.2.2.1. River Blythe.

- Over-abstraction: agriculture is the main cause of over-abstraction, which affects the whole river ecosystem.
- Eutrophication/excess nutrients: this derives both from agricultural fertilisers and from discharges from sewage works.
- Other pollution occurs from run-off from the many roads in the area, and from incidents involving oil, sewage, chemicals and organic wastes.
- Urbanisation: continuing urban expansion in the area places considerable development pressure on land around the river, and has resulted in increases in both abstractions for the public water supply and discharges from sewage works.
- Siltation: this derives from soil erosion from agricultural intensification, and from run-off from roads, affecting the ecosystem.
- Extraction: gravel is taken from the lower Blythe, which affects the ecosystem.
- Poor river management, involving excess drainage of wetlands, again with impacts on ecosystems.

The pressures on water quality from various pollution sources mean that a decline in the river's aquatic life has been observed since a survey in 1981. It is clear that if the range and level of environmental functions of the river Blythe are to be maintained, decisive action on the above issues will need to be taken.

2.2.2.2. River Trent. As noted above, the Trent has a long history of extensive pollution by industrial chemicals and wastes, and by sewage. Much of the industrial pollution has now been controlled, but still occasionally presents a problem. More serious now is the sewage pollution with over 90 combined sewer overflows discharging into the river. To this pollution is added run-off from roads and a number of heavy goods vehicles parks, as well as from intensive agriculture. Upstream of Stoke-on-Trent dredging for flood defence has also had a major impact on the river's ecosystems.

This brief discussion shows that the environmental sustainability challenges facing the two rivers, the Blythe and the Trent, have both similarities and differences. Similar are the types of pollution, which need to be controlled-agricultural run-off, sewage and company discharges. The main differences arise from the fact that the relatively good water quality of the Blythe places it under greater stress from over-abstraction for both agriculture and the public water supply. The Blythe's water quality, and relatively natural condition, also means that it is of high nature conservation interest, which is threatened by over-abstraction, pollution and urban development.

On the other hand, the long-term very polluted state of the Trent means that it has not been regarded as suitable for water abstraction for a considerable time. This pollution, together with the extensive intervention in its flows for industrial purposes, has also greatly reduced its interest in terms of wildlife and biodiversity, and in terms of recreational opportunity.

Thus the two rivers provide a very clear contrast in terms of the environmental functions they perform, and this has great implications for the kind of management that is necessary for environmental sustainability.

2.2.3. Sustainability standards and gaps

As noted above, the river Blythe performs important source, life support and human welfare functions, as well as acting as a sink for wastes from human activities. The river Trent is now largely limited to performing sink functions. This difference makes the standards and targets of environmental sustainability (the maintenance of important environmental functions) for the two rivers quite different.

For the Blythe, maintenance of its life support functions will require strict limitation of abstraction, and stringent controls both on emissions to the river (even though these emissions are already very low compared, for example, with the Trent), and on further urban development. For the Trent, its long historical use as a sink means that, in the stretch considered, it performs very few source, life support or human welfare functions. Increasingly this principal use of the river as a sink is becoming regarded as unsustainable. There are strengthening demands for some of the source functions (for example, abstraction of water for the public water supply), life support functions (support of fish and other aquatic life) and recreation functions (for example, angling) to be restored. This will require very considerable investment, to reduce the extent to which the Trent is used as a sink, especially for untreated sewage.

The environmental sustainability challenges facing the two rivers can therefore be expressed in terms of conservation of functions for the river Blythe, and restoration of functions for the river Trent. From this perspective closing the environmental sustainability gaps for the river Blythe requires:

- Strict limits on new abstraction licences, and non-renewal of some existing licences when they expire.
- Further control of pollution by nutrients from agriculture and sewage treatment works, to enable the Blythe to reach the river ecosystem classification, which is necessary for it to maintain its natural diversity and scientific conservation interest.
- No further release of green-belt land for housing and industry, and improved water drainage techniques to reduce run-off from existing urban areas.

For the Trent closing the environmental sustainability gap requires the restoration of environmental functions, as discussed above. The most important issue concerns the reduction in pollution flows, the principal contributors to which are combined sewer overflows, with important secondary pollution sources being industrial plants, surface run-off and agriculture. Only then will water quality improve enough to permit abstraction of water for the public water supply and the support of fish and other aquatic life, required for both ecosystem diversity and angling and other leisure and recreation pursuits.

2.2.4. Socio-economic implications of policies for sustainability

The socio-economic implications of the environmental sustainability programmes for the rivers Blythe and Trent are very different, as their different situations and objectives would suggest.

Intensive use of the Trent's sink functions over many years has meant that for a long time it has not performed, or been expected to perform, other functions (source, life support or human health and welfare). Recently, however, improvements in the Trent's water quality have made it possible to consider using the Trent's water in the public water supply, and shortages of water from other sources have made this very desirable. This would, however, require further substantial investment in pollution control and ecosystem restoration.

Due to low public expectations of the river, there has historically been little demand for such investment. Now, however, there is increased leisure time and appreciation of the opportunities offered by a high quality river. Increasingly good quality rivers are regarded as important recreational resources. The local authority, mindful also of the development opportunities offered by high-quality waterside locations, has been keen to stimulate public awareness of the river's recreation potential, and demand for that potential to be realised. The EEA (1999) has noted that the trend of increasing sewage treatment has been a major cause of water quality improvement throughout Europe, and that continuing implementation of the 'urban waste water treatment directive' should ensure that this improvement is sustained. Such treatment should greatly reduce the impacts from sewage discharged into the Trent, and significantly improve the quality of the river by itself.

For a river in the Trent's condition, therefore, limitation of its use as a sink just by providing more sewage treatment would serve to increase its source, life support and human health and welfare functions. A sustainability programme may, therefore, be expected to win support from a variety of interest groups: water supply companies, the local authority, ecological scientists, environmentalists, and anglers and others with leisure and tourism interests in the riverside (for example, public houses along the river, or boat hire companies). This alliance of interest groups will make it significantly easier to mobilise the necessary investment for the Trent sustainability programme to be implemented.

Implementing the sustainability programme for the river Blythe is likely to be more problematic. Limiting abstraction for the public water supply and spray irrigation will not be popular with water supply companies and farmers. The former group may also resist new restrictions on discharges from sewage treatment works, but, in any case, by themselves these will not suffice to achieve the necessary high levels of water quality to safeguard the ecosystem. For this, limits on the use of agricultural chemicals will also be required. EEA (1999) reports that effective control of nitrate run-off from agriculture is very difficult and has rarely been achieved in Europe. It is likely to be resisted by farmers adjoining the Blythe. Refusals of planning permission for green-belt development will be opposed by developers, and reduce taxes to local authorities. The required biodiversity conservation measures will not significantly improve the river visually, and may require restrictions on angling. General public access to the river will also need to be controlled, so that it does not interfere with wildlife. In fact the only interest group likely to be strongly in favour of a sustainability programme for the river Blythe is ecological scientists, supported by environmentalists who also understand the importance of biodiversity. Other groups are likely to be at best neutral, and at worst strongly hostile to the programme. Such a balance of interests is likely to make implementation of the programme, and achievement of its objectives, more difficult than in the case of the Trent.

The contrasting situation with regard to the environmental sustainability of these two rivers illustrates what might be called the phenomenon of 'functional progression' in a country like the UK. At high levels of pollution and environmental degradation, it is possible to increase the range and levels of a river's environmental functions in ways that bring benefits to a number of interest groups. This makes it more likely that the investment to improve the quality of the river will be found, and that opposition to such improvement from those negatively affected by costs associated with it will be overcome.

However, maintaining (or achieving) the much higher levels of environmental quality required to sustain scientifically important levels of biodiversity will be much less likely to bring benefits to a broad range of interest groups. Indeed, it is far more likely to impact negatively on their interests. This leads to the conclusion that the maintenance of high levels of biodiversity is likely to be among the most difficult objectives of environmental sustainability to realise. The continuing decline of biodiversity across Europe, with regard to river ecosystems and more generally, strongly suggests that this is indeed proving to be the case.

2.3. Germany: forests[4]

2.3.1. Natural capital characteristics and functions

Like other complex ecosystems, forests perform a range of environmental functions. Source functions include the provision of wood for timber and fuelwood, of other forest products (e.g. berries, mushrooms), of game (for hunting and trapping), and of water (especially in watersheds, where forests can play an important role in storing water). Sink functions include the filtration and cleansing of pollutants from the air, and the sequestration of atmospheric carbon dioxide. Life support functions include the provision of habitats for a wide range of animal and plant species, the protection of soil from erosion and desertification and reduction in the risk of avalanches, and regulation of the climate and of waterflow. Human health and welfare functions include the provision of attractive landscapes and areas for recreation.

The traditional focus of German forestry has been the sustaining of forest yields, principally of timber. Over 90% of German responses to a survey in 1990 gave a low importance to the life support functions of forests, stressing instead the importance of wood production and of hunting. This is a clear example of importance being attached to 'functions for', without widespread appreciation of how sustaining these 'functions for' depends on the maintenance of the 'functions of' the ecosystem. While there is now greater conceptual emphasis on sustaining a wider range of forest functions, management practices at the individual forest level are slow to change. One result is that forest biodiversity in Germany is under great pressure: 47% of forest-based plant species are endangered.

2.3.2. Sectoral pressures

Environmental pressure on forests is derived from two main causes: unsustainable timber extraction (37 million m^3 in 1995–1996, up 30% from 3 years earlier), and forest damage from a variety of factors, including air pollution.

Timber extraction is not unsustainable in the sense that the forest area is being reduced; it is in fact relatively constant at about 30% of the German land area, and in Europe is estimated to have increased by 10% over the last 30 years (EEA, 1995). Rather it is that forestry operates mainly through clear-cutting and single-species plantations, which greatly reduces forest biodiversity. Very few natural undisturbed forests remain in Germany, and only 0.2% of the total forest area is classified as natural forest reserves. Another activity, which damages forest biodiversity is hunting, to provide for which the stock of game tends to be maintained at too high a level for the ecosystem.

A number of complex stress factors, including management practices and air pollution (principally from power generation and road transport), seem to have combined in a way that is still not fully understood to produce the new forest damage that first became apparent in the early 1980s. While intensive monitoring of the situation, and various measures including the reduction of sulphur pollution, may have resulted in the situation improving slightly during the 1990s, still in 1997, 39% of the main tree species showed damage and 20% showed significant damage.

[4] Summarising 'Applying the CRITINC framework to the forest sector in Germany' by Christiane Beuermann (Wuppertal Institute).

2.3.3. Sustainability standards and gaps

The recent development of and emphasis on the concept of 'sustainable forestry', where it is the full range of forest functions that is intended to be sustained, has led to a plethora of initiatives seeking to develop standards and management practices by which it can be achieved. A number of these derive from the forest principles agreed at the Rio summit in 1992, and most international regions are now covered by processes, declarations and working groups that are seeking to put these principles into practice for different types of forest. The case study focuses especially on the criteria and indicators, which have been developed and tested by the Centre for International Forestry Research (CIFOR). These are structured round four themes: general organisational information; ecological principles; economic principles; and socio-economic principles. A number of test projects have sought to elucidate the implications of putting these principles into practice in specific forest situations.

2.3.4. Socio-economic implications of policies for sustainability

So far the implementation of principles of sustainable forestry is in its infancy, and little can be said about the overall implications for the forestry industry of systematic moves towards forest management practices that give more weight to the nature protection and conservation functions of forests. One complication in the elaboration of any Europe-wide system of sustainable forestry certification is the great difference in the ownership structure of forests, which exists in the countries of the European union. For example, the public/private ownership split ranges from 85/15 in Ireland to 10/90 in Portugal, with a full range of combinations in between and an average of 41/59. The private forest estates also vary greatly in size, ranging from large-scale plantations to very small plots (the average size of French private forests is only 3 ha). It will be a great challenge to develop practices for sustainable forest management, which can be effectively applied across such a broad range of institutional arrangements.

2.4. Sweden: ecosystem functions in urban areas[5]

2.4.1. Natural capital characteristics and functions

Stockholm county in Sweden has a population of 1.8 million people and, with a density of 248 persons per km^2, is relatively densely populated by Swedish standards. However, only 17% of the county is urban land, while nearly half is forested, 12% is arable land, 11% is mountains and 10% is water.

Green space in cities performs a variety of environmental functions of benefit to humans, including sequestering carbon dioxide emissions, improving air quality and the city climate, regenerating water stocks and regulating water flows (e.g. through rainwater drainage), treating sewage, providing attractive spaces for recreation and amenity, reducing noise, and providing habitats and refuge for animal and plant species. In order to perform these functions, the ecosystems of Stockholm county must sustain themselves through their own use of natural resources. Using the concepts discussed earlier, provision of these ecosystem's functions for humans depends on the maintenance of the environmental functions of the ecosystems.

This case study focused on two benefits for humans provided by the ecosystems of Stockholm county: the CO_2 sequestration functions and the provision of freshwater. The study then calculates how much freshwater the ecosystem requires for its own maintenance in order to deliver these benefits for humans. The case study finds that the ecosystems of Stockholm county sequester about 14% of the CO_2 emissions of Stockholm county's human population, and require for their own maintenance about ten times as much water (much in the form of water vapour) as the direct appropriation of freshwater of Stockholm's residents. This flow of water vapour is largely invisible. For example, in the EEA's framework of indicators of urban flows (of water, energy, materials and products, and wastes, EEA, 1995,

[5] Summarising 'Human dependence on functioning natural capital: the case of Stockholm county' by Åsa Jansson and Peter Nohrstedt (Stockholm University).

Table 10.1), the flows are exclusively those related to human appropriations and activities. While the importance of urban green space is acknowledged in the indicators of urban environmental quality, there is no explicit recognition that this green space requires resource flows for its own maintenance. The danger is that this will result in an excessive quantity being diverted for human use, or that human interventions will make it otherwise unavailable, so that the ecosystem functions which it sustains will be inadvertently lost (Jansson and Nohrstedt, 2001).

2.4.2. Sectoral pressures

The continuing growth of Stockholm and the associated construction of housing and urban infrastructure means that the ecosystems which provide environmental benefits to the residents of Stockholm county are being progressively lost. Generally this loss, which represents real costs, is neither calculated nor recorded, so that the extent of the changes taking place are unlikely to be optimal. Moreover, such changes are taking place all over Europe. The increasing emphasis in urban design on the concept of 'the compact city' means that urban green spaces are increasingly being lost.

2.4.3. Sustainability standards and gaps

Compared with the surrounding areas of other major European cities, Stockholm county still has a very low proportion of urban land. Because of the ability of residents of urban areas to appropriate ecosystem services (e.g. for carbon sequestration or the provision of freshwater) from outside the city, it is not possible to specify firm sustainability standards for the amount of urban green space, and associated ecosystem services, which cities should seek to retain. However, what is sure is that the ability of hinterlands to provide ecosystem services to cities is not infinite, and that the loss of ecosystem services to urban residents represents a cost which at the very least should be give due weight in the decision-making process, rather than remaining largely unaccounted for as at present.

2.4.4. Socio-economic implications of policies for sustainability

As cities grow throughout the world the development pressures on urban green space are likely to increase. The compact city concept has a number of environmental advantages, such as a greater intensity of use of infrastructure or transport, but these advantages should not be allowed to obscure the real costs associated with the loss of urban natural or semi-natural areas. Stockholm county's green areas are still of an extent and ecosystem complexity to provide a more balanced nature-human environment than exists in most European cities. It is certain that, if this balance continues to be eroded by urban growth and economic development, the residents of Stockholm county will, where possible, have to provide substitutes (e.g. sewage treatment works) for the ecosystem services which are lost, or will experience a decline in their quality of life. The analysis of ecosystem functions in this case study at least provides a methodology whereby these costs can be made apparent so that they may be taken into account in decision making (Jansson and Nohrstedt, 2001).

2.5. Netherlands: coastal wetlands[6]

2.5.1. Natural capital characteristics and functions

The Wadden Sea is the largest stretch of intertidal mudflats, and one of the largest wetland areas, in the world. It forms part of the coastline of three countries, Denmark, Germany and the Netherlands, which share its jurisdiction. The Dutch Wadden Sea was the focus of this case study.

As an extensive ecosystem, the Wadden Sea performs a wide range of environmental functions across all four categories of the CRITINC framework: air, water, land and habitats. It plays a role in climate and water regulation, protects against soil erosion, purifies and filters wastes and fixes large quantities of solar energy. In terms of

[6] Summarising 'Coastal wetlands: the Dutch Wadden Sea' by Johan van der Perk and Rudolf de Groot (Wageningen University).

biomass production, this area is among the most productive systems in the world. This high primary productivity means that it is an important nursery of and refuge for North Sea populations of plants, birds and all kinds of marine life. It provides significant quantities of marine foods and non-metallic minerals. It is also an important area for recreation, artistic and spiritual inspiration and scientific research. The case study shows that it performs 15 distinct environmental functions in these areas.

The Wadden Sea provides a clear example of the distinction between 'functions of' the environment, and 'functions for' humans, and associated complexities, which were noted above. Clearly the Wadden Sea performs many functions of direct benefit to humans. But equally clearly it is only able to do this if the internal environmental functions of the Wadden Sea continue to maintain its diverse ecosystem characteristics and productivity.

Increasingly the different functions of the Wadden Sea are in competition with each other at the levels at which demand for them is now being experienced. The result is that the Source functions, for both renewable and non-renewable resources, are not being used sustainably; overuse of both the source and the sink functions is threatening the integrity and life support functions of the ecosystem; and demands by too many people for space and recreation facilities are interfering with the Wadden Sea's ability to provide an experience of natural wildness and with its wildlife. By all the criteria and principles of environmental sustainability listed above, the Wadden Sea qualifies as CNC. However, its wide range of functions, due to the continuing over-use of some of them, is in unprecedented danger of being lost.

It will be apparent that the Wadden Sea is, to some extent, a unique ecosystem. But the threats facing it are shared by many other coastal areas in Europe. The Baltic sea, the Mediterranean, the Black sea, and many other European coastal areas, all perform similar environmental functions, and are faced by similar challenges. EEA (1998) noted that 'the substantial losses of wetlands of the last 100–150 years are continuing despite most countries now having wetland protection schemes'. However, the rate of loss is declining in many areas and is now least in Northern areas of Europe.

2.5.2. Sectoral pressures

A number of economic sectors exert pressure on the Wadden Sea. One of the most long-standing sources of pressure has been land reclamation, which has greatly reduced the extent of the Dutch Wadden Sea, and closing off of waterways, which has affected fish migration and salinity gradients. Sectors that extract renewable or non-renewable resources are fishing, hunting, mineral extraction and tourism (through its use of freshwater). Recently proposals have been put forward for the large-scale extraction of natural gas. Polluting sectors are agriculture and horticulture (nutrients and pesticides), industry (heavy metals and chemicals) and tourism.

Due to its importance as a nursery for wider North Sea fisheries, over-fishing in the Wadden Sea, and other activities which damage this function, have serious implications for all countries with a North Sea fishing industry.

2.5.3. Sustainability standards and gaps

Sustainability standards for a complex, multi-functional ecosystem like the Wadden Sea are bound to reflect that complexity. It will be necessary, for example, to identify different types of standards, such as:

- standards which distinguish between 'functions of' and 'functions for', and,
- standards, which are based on ecological criteria, and those that derive from human values.

Criteria for the maintenance of 'functions of' will always have an ecological basis, but so will some of those concerned with 'functions for', most obviously those providing renewable resources like fish, freshwater or shells. The case study notes, for example, that, despite there being a substantial annual generation of shells by the ecosystem, the extraction of shells for use as a construction material is so much in excess of the sustainable level that the very considerable original stock will be fully depleted in 35 years.

The criteria for functions for human health and welfare (HW) will tend to be based on human values. There may be conflicts within the categories of ecological and human criteria, or between them. The set of sustainability standards for the Wadden Sea environmental functions overall, therefore, requires careful integration in order to reflect the very wide range of purposes towards which these functions are directed.

With a few exceptions, such as the harvest of shells mentioned above, the case study did not proceed so far as to give quantitative estimates for the sustainability standards to be applied to the Wadden Sea's environmental functions. But it did identify the key concepts, including, among the ecological criteria, sustainable yield, carrying capacity, minimum critical ecosystem size and critical thresholds (qualitative, quantitative and spatial). Given the difficulty of determining some of the variables for a highly dynamic ecosystem like the Wadden Sea, and the great reduction in its surface area and populations of some of its species of animals and plants which have already taken place, one means of estimating the sustainability of the ecosystem as a whole would be to compare its current extent and characteristics with those of the Wadden Sea prior to human intervention and impacts. Any trend of further reduction and deterioration would then clearly not be sustainable, and the aim of sustainable development over time could be to reduce the gap between the existing Wadden Sea and its initial natural state.

It is not possible to give hard and fast standards for the HW functions of the Wadden Sea, for those functions engender mental health, and aesthetic and spiritual welfare, the necessary or desired levels of which derive from socio-cultural criteria and values, which have not yet been made explicit, and which in any case may change over time. However, appreciation of the importance of these functions would appear to be growing, as is the impetus of political processes which would maintain them at close to current levels (for example, the reported move away from mass tourism towards nature-based tourism). These processes are unlikely to result in a definitive specification of a 'sustainable' level of the HW functions of the Wadden Sea. Rather the level achieved, once there is adequate awareness of the issues involved, and an institutional structure to give that awareness political expression, will reflect the socio-cultural valuation of these functions that then pertains.

2.5.4. Socio-economic implications of policies for sustainability

The three countries with coasts on the Wadden Sea have sovereignty over the parts they adjoin, but they have signed a Joint Declaration on the Protection of the Wadden Sea and a policy 'with the aim of wise use and appreciation of precautionary principles in regional planning' (EEA, 1995). A management plan for the Wadden Sea was agreed in 1997, with the aim of restoring and developing its outstanding ecological features, without excluding people from the area. Progress in achieving the numerous targets in the plan will be reviewed in 2002 (EEA, 1999).

As noted in the case study, in some respects conditions in the Wadden Sea are improving. Populations of some species are increasing and the ecosystem is slowly 'detoxifying' itself from pollutants, which are no longer emitted into the environment. The case study goes into little detail about the opportunity and other costs that will need to be borne if the benefits from the environmental functions of the Wadden Sea are to be maintained and, where necessary, restored, in line with the criteria and principles of environmental sustainability. Doubtless there will be some difficult decisions ahead.

2.6. France: agricultural land and water resources[7]

2.6.1. Natural capital characteristics and functions

Water resources in the French region of Brittany perform a number of important environmental

[7] Summarising 'Environmental Evaluation and Critical Natural Capital: the Case of Water Quality Degradation Linked to Agriculture in Brittany' by Jean-Marc Douguet (C3ED).

functions. They provide drinking water for the local population and, because of a lack of availability of groundwater, much of this function is provided by surface waters. Water is also an important input into agriculture and several associated industrial sectors, as well as some other industries. Brittany also has important fish farming and fishery activities, both in its freshwaters and on the coasts. Furthermore, Brittany is one of France's most important tourist regions, to which its water resources make a major contribution, through sport fishing, swimming, other water sports and the provision of attractive coastal holidays. Water is, therefore, a very important economic resource in Brittany, as well as being an essential element in the functioning of its ecosystems.

2.6.2. Sectoral pressures

In recent decades the agriculture sector in Brittany has been transformed from relatively low-output, small-scale mixed farming to a very intensive agriculture. Between 1970 and 1996 milk production increased by a factor of 3, pig production by more than a factor of 4, and fowl (chickens and turkeys) production by more than a factor of 6. Wheat production also increased by a factor of 4, and maize production (for animal feed) increased by a factor of 20.

The emissions from the enormous intensification of agricultural activity have seriously affected water quality. Between 1972 and 1994 average nitrate levels in Brittany increased from 8.5 to 39 mg l^{-1}, and samples now regularly exceed the 50 mg l^{-1} limit specified by the European drinking water directive. The concentration of a number of pesticides in surface waters also frequently exceeds EC norms. The increase in nitrates in surface waters has also caused eutrophication of waters, with serious episodes of algal blooms round the coasts. It can, therefore, be seen that development of one economic sector, agriculture, and the consequent use of the region's water resources as a sink, is having profound effects on the availability of water for other functions, most obviously for its use as drinking water, but also for fish farming and for use and appreciation by tourists. It may be noted that this problem is not unique to Brittany. EEA (1999) notes that the EU Directive on nitrate pollution from agriculture has been unsatisfactorily implemented in a majority of EU Member States, and progress with regard to the Directive on pesticide pollution has been 'glacially slow'.

2.6.3. Sustainability standards and gaps

Sustainability standards for water quality, in terms both of its suitability for drinking and in terms of prevention of eutrophication, are well defined. As noted above, they are currently regularly exceeded in Brittany, and it is forecast that, on current trends, two thirds of water abstractions in Brittany will exceed European standards for drinking water. This is probably the single most obvious example of an unsustainable trend that has been identified in the CRITINC project.

2.6.4. Socio-economic implications of policies for sustainability

Policies for the environmentally sustainable use of water resources in Brittany clearly involve a change in farming practices and priorities. Using a linked economy–environment model, the case study examines the implications of three possible changes: a more rational use of intensive farming methods (1); low-input farming methods with more emphasis on environmental protection (2); and organic farming methods (3). Of these options, (1) reduces the level of agricultural production the least, but also both improves environmental quality the least and has the lowest cost-effectiveness of necessary environmental improvement, because of the expense of the required water-pollution treatment measures. Options (2) and (3) achieve broadly comparable improvements in environmental quality, and at broadly comparable marginal costs of improvement, with the difference that for option (2) the marginal cost rises from 2010 to 2020, while for option (3) the marginal cost falls over the same period.

While the case study emphasises that these results require further refinement and should be regarded as indicative only, the treatment of the issue provides a clear example of the strength of the CRITINC approach to issues of environmental unsustainability: competition between environmental functions and the sources of environmental pressure can be clearly identified; standards for environmental improvements can be specified; and the economic and social implications of different transition paths to compliance with these standards can be modelled and analysed, in order to give decision support on which policies may be implemented most cost effectively.

3. Summary conclusions

The CRITINC project made a number of theoretical and practical advances.

On the theoretical side, it deepened the understanding of critical natural capital and environmental sustainability in several ways:

- It emphasised the joint importance of the elements of natural capital, the interactions between those elements and the processes to which these interactions give rise. It is this complexity which enables natural capital to perform its functions, and which must remain the focus of analysis if the processes which perform the functions are to be understood, and the functions sustained.
- It is important to distinguish between the functions of the environment, which sustain ecosystems, and the functions, which these ecosystems then perform for humans. The latter are more obvious and more likely to be valued, but they depend entirely for their continuance on the sustained operation of the former.
- Three fundamental criteria for environmental sustainability were found to be: the maintenance of human health, the avoidance of threat and the maintenance of economically valuable functions. These criteria allow seven sustainability principles to be developed, from the application of which environmental sustainability standards may be derived, and hence measurements of the gap between the standards and current practices or situations. This permits the concept of environmental sustainability to be clearly indicated by quantitative measures, which makes it far more amenable to application in practical management.
- Policy measures may be developed to reduce the sustainability gap, from which the socio-economic implications of moving towards environmental sustainability may be elaborated.

In this way the CRITINC project developed a clear methodology for the practical application of the ideas of critical natural capital and environmental sustainability, which is of great potential use to environmental policy makers.

The methodology was applied to a number of case studies covering a diverse range of environmental issues. The case studies focused on different stages and elements of the methodology, but in each case the method enabled the full contribution of the environment to the subject of the study to be analysed. Different insights emerged from the different case studies, as discussed above, but a common outcome of the studies was the clear articulation of whether the situation in question was moving towards, or away from, environmental sustainability, and what the causes of the movement were. In each case the policy measures required to reduce the sustainability gap were well defined, so that their socio-economic implications could be made apparent.

The Introduction to this Special Issue began by quoting from various sources to the effect that the general situation of environmental unsustainability was acute, was deteriorating in many countries, and could prove to be catastrophic. The CRITINC methodology allows these processes to be clearly revealed and understood, responses to slow down and eventually reverse the trends of deterioration to be formulated, and the implications of these responses to be explored. Obviously the actual implementation of the policies will depend on the social and political commitment to environmental sustainability. What the methodology reveals is whether any policy responses to environmental unsustainability are being effective, whether they are actually addressing the problems that are giving increasing cause for concern. This would seem to be useful attribute in a policy area which is much characterised by worthy rhetoric, but in which really effective practical action is much rarer.

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