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ANALYSIS

Natural capital and quality of life: a model for evaluating the sustainability of alternative regional development paths

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Abstract

Natural capital contributes to the quality of life of a region in two complementary ways: first, by directly providing environmental services that cannot be imported, and second, by supplying the natural resources that, through a human controlled production process, become valuable to humans. The evolution of the combination of these two components of the quality of life determines the path of development a region takes. Environmental services also determine the ability of natural capital to regenerate itself. Ecosystems and other components of the regional natural capital produce environmental services that provide life-support functions necessary for natural capital reproduction. The destruction of this critical natural capital impairs the internal sources of improvement of the quality of life of a region, leading to a non-sustainable path of development. This article describes a model of the relationship between natural capital and quality of life that provides a stricter definition of sustainable development through explicit characterization and classification of natural capital according to its ability to produce life-supporting environmental services, by its substitutability, and by its possible reconstruction. Application of this model then shows that there are 51 possible regional development paths, only 32 of which are sustainable and only 14 of which are sustainable while also providing improvements in quality of life. Only six of these 14 sustainable development paths are attained with economic growth, however, while the other eight paths increase quality of life by increasing the production of environmental services. The model could help in the development of institutional interventions that would promote regional development paths that are sustainable. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The concept of sustainable development has been widely debated since the publication of the Brundtland Commission report in 1987 (World

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Commission on Environment and Development, 1987), and the economics literature has developed several models of sustainability that are useful for policy discourse (Turner et al., 1994). These models remain conceptual frameworks, however, that lack the specificity and precision necessary for application to the problem of regional economic development. In this article we develop a more detailed model of strong sustainability that differentiates classes of natural capital in ways that could support the development of meaningful institutional interventions for sustainability at the regional scale. In doing so we delineate how natural capital is linked to quality of life in ways that traditional models of economic development fail to consider.

The stocks that produce ecological and economic goods and services used by humans can be classified as human-made and natural capital. Natural capital is usually divided into two major subtypes: non-renewable resources, such as oil, coal and minerals; and renewable resources such as ecosystems. Ecosystems are sources of raw materials and food, and also provide a wide range of environmental and ecological services, which include maintenance of the composition of the atmosphere, maintenance of climate, operation of the hydrological cycle, waste assimilation, recycling of nutrients, generation of soils, pollination of crops, maintenance of biodiversity and landscape, and aesthetic and amenity services.

Natural capital can be destroyed indirectly as a result of contamination from a productive or consumptive process, or directly as a result of its exploitation or fragmentation. The first problem, contamination, which is primarily related to human health, has been extensively studied by the field of environmental economics, and the theoretical frameworks developed have contributed to conservation policies through the market, the regulatory system, or a combination of both. By contrast, the study of the second problem, destruction of ecosystems by exploitation of some of its components, has generally not led to policy conducive to the conservation of natural capital, especially natural capital that is under private ownership. Ecological economics has highlighted the importance of the non-substitutability of natural capital and its complementary role in further development, while seeking to keep the scale of human society within sustainable bounds (Folke et al., 1994). Its contributions have been significant in clarifying concepts and linking the economic system with the environment. Nevertheless, conservation policies that explicitly attempt to conserve some types of natural capital are almost non-existent, except for a few attempts in India and in the US (Gadgil and Rao, 1995; Stone, 1995).

This lack of appropriate policy reflects a paucity of theoretical frameworks that explicitly link natural capital and quality of life at a regional level. The objective of this article is to contribute to this area of study by establishing a more precise theoretical relationship between the use given to different kinds of natural capital by a region, and the long-term effects of their use in terms of human well-being. In particular, we have developed a general model of regional development that will answer the following questions: (1) how does the use of natural capital of the region affect the quality of life of that region?, and (2) which alternative paths of development are sustainable under the model's criteria, which differentiates natural into more precise categories? Moreover, we suggest how the model's categorical distinctions between different types of natural capital can serve as the basis for designing improved institutional interventions to promote sustainable development.

The article begins with a brief review of the literature, presented in section II, and the construction of a theoretical framework that relates natural capital and quality of life in section III. Section IV then discusses the implications of the model for determining the sustainability of alternative regional development paths.

This framework indicates that natural capital contributes to the quality of life of a region in two complementary ways: first, by directly providing environmental services that cannot be imported, and second, by supplying the natural resources that, through a human controlled production process, become valuable to humans. The evolution of the combination of these two components of the quality of life determines the path of development a region takes.

In addition to providing direct benefits contributing to quality of life, the flow of environmental services determines the ability of natural capital to regenerate itself. Ecosystems and other components of the regional natural capital produce environmental services that provide life-support functions necessary for natural capital reproduction. The destruction of this critical natural capital impairs the internal sources of improvement of the quality of life of a region, leading to a non-sustainable path of development.

Our model characterizes natural capital according to: (1) its ability to produce life-supporting environmental services, (2) by its substitutability, and (3) by its possible reconstruction. Our model of regional development can therefore provide the basis for the design of institutions that promote sustainable regional development. It is a qualitative model, however, that is meant primarily as a heuristic device rather than a basis for quantifying the various parameters in the model in order to reach precise conclusions about the sustainability of alternative development paths. It nevertheless offers a more precise and operational basis than the existing literature for determining whether development is sustainable or not. Moreover, the model links quality of life to specific classes of natural capital at the regional level. This will help to operationalize the concept of sustainable development at a level that affects people's lives directly.

2. Existing models of sustainable development

In this section we present a brief summary of the predominant views in the literature that relate natural capital and quality of life. We focus here upon the relationship between ecological systems and economic models, although we recognize that the concept of sustainable development includes a social dimension focused on considerations of equity (Sachs, 1992; Munasinghe, 1993; Berkes and Folke, 1994; Munasinghe and Cruz, 1995).

2.1. The traditional model

The concept of sustainable development has its roots in the classical economics theories of the eighteenth and early nineteenth centuries, where the works of Ricardo, Malthus and Mill developed the concepts of limits to growth. Malthus based his limits to growth argument on the concept of absolute scarcity, determined by the fixed amount of land available, that would force population to cease to grow. Ricardo based his argument on the diminishing returns of land because of its non-homogeneous quality. He argued that an expanding population has to use land that is less fertile, reducing the standards of living of the population, forcing it to stop growing. Mill also thought that a stationary state could not be prevented because wealth would have to stop growing at some point. He was more optimistic than Ricardo about the steady-state, believing that a better distribution of wealth would be accomplished as a consequence of individual prudence and frugality and legislation by the state.

Marxism and neoclassicism introduced new concepts that altered the views on sustainability in the mid-eighteenth century. Marx considered progress as a natural process, and defined it as the material and technological advance made possible by the exploitation of nature. He did not directly address the problem of limits to growth, but emphasized the fact that a system is viable only if it can reproduce itself, which, according to modern Marxian writers, is a hint that the natural system can set limits to progress (Pearce and Turner, 1991).

The neoclassical economic paradigm, starting around 1870, shifted the emphasis from long-term consequences to short-term outcomes through the use of marginal analysis. Clean air and water and ecosystem services are considered public goods that, because of their non-rival and non-exclusive characteristics, have to be provided with government intervention. Price corrections (primarily through the application of Pigouvian taxes) are typically characterized as the most appropriate public policy tools to restore an improved level of efficiency in cases of negative

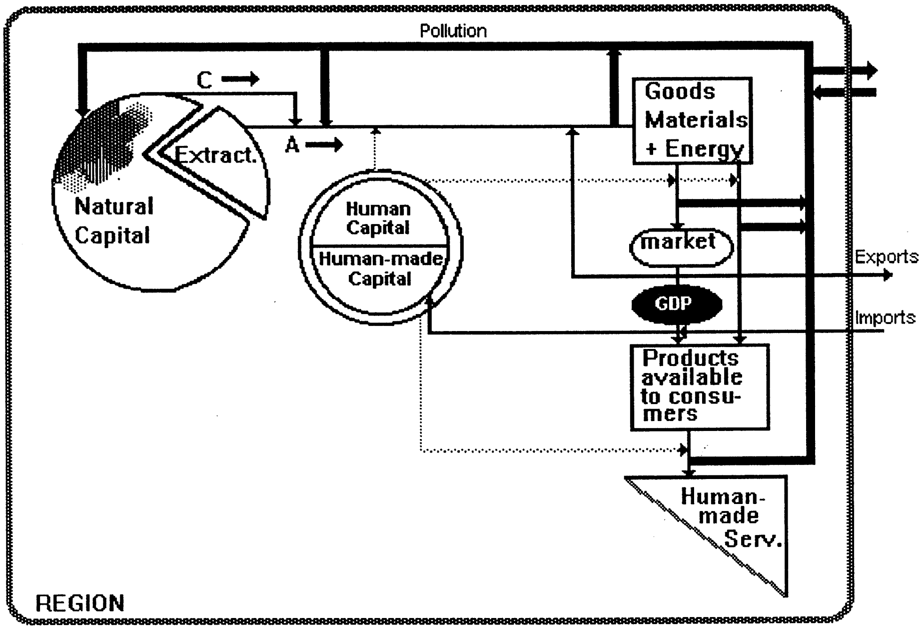

Fig. 1. Traditional view. Thin arrows: Processes that contain natural resources: Production processes (A and C), distribution, consumption and import-export. Thick arrows: Waste; Dotted lines: Processes without natural resources component. Some processes in this figure have been kept simple: distribution—makes processed materials and energy, including intermediate and capital goods, accessible to consumers and producers, some occurs through the market, some dont; consumption—changes materials and energy into services; import-export—bring materials and energy in and out of the region.

externalities produced by private parties, ostensibly leading to 'optimal pollution levels' (Baumol and Oates, 1979; Ortolano, 1997).

Neoclassical economics considers the economic system to be separated from the natural and other social systems. Natural capital is only a source of materials that comes into the production process at no cost, except the cost of extraction. Development is defined as increases in gross domestic product (GDP), and can be accomplished with an efficient price system that reflects scarcity and stimulates technical improvement. This technical change counteracts depletion by substitution and by facilitating extraction. Substitution among different kinds of capital (and among capital and labor) is infinite, depending only on technological change (this is an assumption of both Bator and Cobb–Douglas analyses).[1] The irreversibility of damage to natural capital is therefore not an issue.

The sustainability criteria derived from this view is highly influenced by the assumption of complete substitutability between the factors of production, including natural capital. Economic development is sustainable if the overall stock of assets remains constant over time. Any one asset can be reduced as long as another asset is in-

[1] Bator analysis for the determination of the best configuration of inputs, outputs, and commodity distribution for a two-input, two-output, two-person situation uses land and labor as perfectly substitutable inputs (Bator, 1957). The Cobb–Douglas analysis determines value added as a function of capital stock and employment, which can be substituted among themselves as long as neither input goes to zero (Heathfield and Wibe, 1987).

creased to compensate for it. This is what has been called very weak sustainability (Turner et al., 1994).

A regional model of these views can be summarized in Fig. 1, showing the relationship of the economic system with natural capital.[2]

Natural capital includes all natural assets (i.e. everything that is not human-made). It can be altered by humans, and its reproduction can be enhanced by humans, but it cannot be created by humans.[3] According to this model, natural capital generates two kinds of production processes, A and C. Process A starts with extractive activities, while process C obtains natural resources without destroying ecosystem integrity.[4] Both can use recycled waste. With the intervention of people (human capital, which is a function of both labor inputs and the structure of social institutions), and human-made capital, this process creates material goods and energy that are distributed, with or without the intervention of the market, and made available to consumers and producers. These goods and energy are transformed into human-made services through a consumption process.

The most problematic assumptions of this paradigm in relation to the use of natural capital and its potential to produce environmental services are: (1) it uses a narrow definition of development, which includes only part of human-made services as contributing to development; (2) it requires a price system that accurately reflects scarcity; (3) it requires a high degree of substitution among different kinds of capital; (4) if working well, it allocates resources to where they are most needed, but takes them from where it is less expensive to extract in traditional cost terms, not necessarily least costly in environmental services terms. It is, therefore, efficient only if all externalities are internalized through accurately-set Pigouvian taxes.

From this framework derives the proposition that economic growth improves environmental quality ('inverted U-shaped curve') (Arrow et al., 1995). This relation has been supported by a weak empirical relation between the growth of the income per capita and a decrease in a subset of pollutants in some developed and underdeveloped countries (World Bank Development Report, 1992). The data considered does not include the destruction of natural capital or other forms of environmental degradation, however, and increasing income per capita is associated with continuing increases for some pollutants. Moreover, the 'inverted U-shaped curve' for pollutants sometimes shows a 'rebound' effect with increasing levels of income per capita that can turn it into an 'N-shaped curve' (Opschoor, 1998).

2.2. Environmental economics

Environmental economists propose two variants to the neoclassical approach. The first is the property rights approach, which offers a market solution to externalities (in contrast to the Pigouvian taxes approach). It maintains that by re-defining property rights these pollution problems can be solved by polluters and sufferers through bargaining, and no state intervention should be necessary (the basis for this approach is an interpretation of Coase, 1960). This solution allocates resources efficiently if the rights are widely recognized and easily enforced, but it does not consider the income distribution effects of assigning property rights, or the transaction costs involved in bargaining or enforcing property rights.

Most of the theoretical contributions of environmental economists deal with the effects of pollution on natural capital, and the possibility of internalization of these negative externalities into the economic system. This body of theory has been the basis for the 'polluter pays principle', and for policies such as tradeable pollution permits. The London School approaches the problem primarily from this perspective (Pearce and Turner, 1991).

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[2] The size of the areas in this and the following figures does not have any meaning.

[3] The categories of natural and human-made capital are not sharply divided. Natural capital can have human modifications, as will be discussed later. Human-made capital is always an alteration of natural capital.

[4] Extraction is defined as any kind of destruction of the integrity of the ecosystem. It will be defined more precisely in Section III, where natural capital categories are explained.

The second variant of environmental economics is the materials balance approach, which introduces entropy limits to the economic analysis. The approach argues that pollution is not only the result of market failure, but an inevitable phenomenon dictated by the laws of thermodynamics, which requires the government to establish some acceptable levels of pollution (Georgescu-Roegen, 1970; Boulding, 1977).

One branch of environmental economics is resource economics, which applies welfare economics principles to determine optimal use and depletion of resources (Fisher, 1981). The goal is, then, the maximization of the present value of the resource to society. In the case of renewable resources this means that the rate of harvesting cannot exceed the rate of regeneration of the resource. In the case of exhaustible resources, it means finding an optimal rate to completely deplete the resource. The Hotelling rule, developed in 1931, indicates that in the simplest case, with costless extraction, the resource should be extracted in a way that the prices rise at the same rate as the discount rate rises. Critics of this model argue that such approaches implicitly assume information about quality and quantity of the resource in question, which is precisely what the models are trying to determine (Norgaard, 1990). Other problems with this model are its absence of concern for future generations' interests, and the implied conviction that technology and substitution will solve the problems after resources are depleted. The policies derived from this approach recommend better management of nature respecting the environmental linkages; economic incentives like prices, credit, and exchange rates; and changes in the tenure of land (Pearce and Turner, 1991).

Natural capital is recognized by environmental economists as an important contributor to human welfare, as a life support system that provides a supply of resources, as a waste receptor, and as a provider of amenities. The opportunity cost of this use is emphasized by authors like Krutilla (1972) and Fisher (1981). The rule for natural capital conservation is that resource stocks should be kept constant over time. The stock of renewable resources should not decline over time (understanding the waste assimilative capacity as a renewable resource), and depletion of exhaustible resources should be replaced by increases in renewable resources or man-made capital (assuming substitutability). This is what has been called weak sustainability (Turner et al., 1994).

These contributions have emphasized the idea that environmental services are important as a component of well-being, and have introduced a general criterion of conservation of natural capital, but do not specify the linkages between the different kinds of natural capital according to its function in producing environmental services and improvements in the quality of life.

2.3. Ecological economics

Ecological Economics represents a major challenge to neoclassical economics by making the socioeconomic system part of the ecological system and addressing the relationships among them. Within this approach it is recognized generally that environmental problems have a structural character and cannot be approached simply by using the concepts of externalities and substitution. The ideas of Boulding, who introduced the relevance of thermodynamics to economics in 1966 (expanded by Georgescu-Roegen in the early 1970s) are very important to the development of this paradigm. In very simple terms, low entropy is the ultimate means of production, and exists for humans as terrestrial stock and solar flow, both limited in practical terms. Based on these constraints (and on an ideal vision of society), Daly in 1977 (Daly, 1991) develops his proposition of a steady-state economics that contemplates structural changes to become less dependent on this scarce source of ultimate means, reaching an optimal rate of matter and energy throughput in the economy equivalent to the external energy inputs.

Co-evolutionary theory, developed by Norgaard in the early 1990s, refers to an ongoing process between social and ecological systems, through feed-back loops, that determines the possibility of development of both. This theory considers economic development as a process of adaptation to a changing environment (while itself being a source of change). Co-evolution can continue indefinitely, reaching equilibria and coming out of them as social and ecological systems evolve. Norgaard (1994) argues that Western science and modernization break this pattern of co-evolution, however, by producing new ways of organizing and new technologies that impose more control over nature, rather than a deeper relationship with it.

The trans-disciplinary field of ecological economics addresses three main goals: first, assessing and ensuring that the scale of human activities is ecologically sustainable; second, ensuring that the distribution of resources is fair within the current generation, between future generations, and between species; and third, efficiently allocating marketable and non-marketable resources under those limits. Natural capital, human capital, and manufactured capital are 'interdependent and to a large extent complementary' (Folke et al., 1994).

The sustainability concept for this paradigm is keeping the life support ecosystems and interrelated socioeconomic systems resilient to change. 'It is not sufficient to just protect the overall level of capital, rather natural capital must also be protected, because at least some natural capital is non-substitutable' (Turner et al., 1994). What is stressed in this approach is the combination of factors (e.g. irrerversiblity and uncertainty), not their presence in isolation. Only if this combination of factors is maintained can we have sustainability. As Daly (1991) notes, 'These services can hardly be produced by any other form of capital, and consequently are complementary to them'. Depletion and pollution make natural capital a limiting factor for further development. This has been called strong sustainability and it distinguishes critical from non-critical natural capital (Turner et al., 1994).

Table 1 summarizes how these different theories conceptualize the relation of the economic and the ecological system, define natural capital, prevent damage to natural capital, cope with scarcity, and define sustainability.

3. Theoretical framework of a regional model

These theories provide an important foundation for designing institutional interventions to promote sustainable development. It is very difficult to use them as a basis for regional policy, however, because these theories are large in scope and are not very specific in establishing the links between natural capital attributes and quality of life. We have therefore extended the concept of strong sustainability here to develop a more precise model of regional development that allows evaluation of the sustainability of different development paths.

3.1. Relationship between natural capital and quality of life

Our model has been designed to explain how the natural capital of a region contributes to the quality of life of that region. The model is primarily based on ecological and coevolutionary economics. It is an adaptation at the regional level that specifically defines the relationship between the different kinds of natural capital and the quality of life of the region in an attempt to make it a framework for policy, development, and evaluation.

In Fig. 2 natural capital is still represented as a circle (as in Fig. 1) for analytical purposes, but it is dispersed irregularly throughout the region as components of ecosystems. This model also adds another production process to the neoclassical view presented in Fig. 1: process B, which generates environmental services. These services are consumed by humans directly, becoming part of the quality of life, and also return to regenerate natural capital. Production Process B does not require human participation (human capital, human-made capital, or technology). Examples of these services are pollination, climate control, natural water purification, maintenance of biodiversity, and aesthetic services. These processes do not compromise the integrity of natural capital permanently because their waste is processed by the natural systems. Some environmental services are indispensable for the regeneration of natural capital, and, in this way, are critical for any kind of development.

The natural capital regeneration rate and ability to produce environmental services is diminished by the waste produced by all of these processes (thick arrows). Its integrity is also diminished due to the extraction or fragmentation of some of its components (Process A).

Table 1
Five views of the economic system and the environment

	Relation economic and ecological system	Natural capital	Prevention and treatment of damage to natural capital	Solutions to scarcity	Sustainability
Neoclassic economics	Separated systems	Materials source Exhaustible: (Hotelling model) Renewable: (harvest = yield)	Pollution treated as externality Taxes Market (legal system)	Technical change, recycling Allocative efficiency and substitution	Very weak = sum all assets constant
London School of Economics (Pearce, Turner)	Connected systems-looks for links, interactions	Inputs Receiving media Amenities	Keep within bounds of assimilative capacity of environment	Substitute exhaustible resources by renewable ones	Weak = renewable conserved, non-renewable replaced by renewable
Ecological economics	Economic system is a subsystem of ecological system	Inputs Receiving media Amenities Environmental Services Biodiversity Complementary to human-made capital	Carrying capacity is the limit to biophysical throughput	Recognizes limits to substitution	Strong = combination of natural capital and human-made capital constant
Steady state economics (Daly, Cobb)	Same	Same	Same	No substitution	Very strong = optimal throughput equivalent to external energy
Co-evolutionary economics (Norgaard)	Adaptive relationship between both	Same	Same	Substitution is part of the adaptive process	Very strong = natural capital and human-made capital maintain an evolving equilibrium

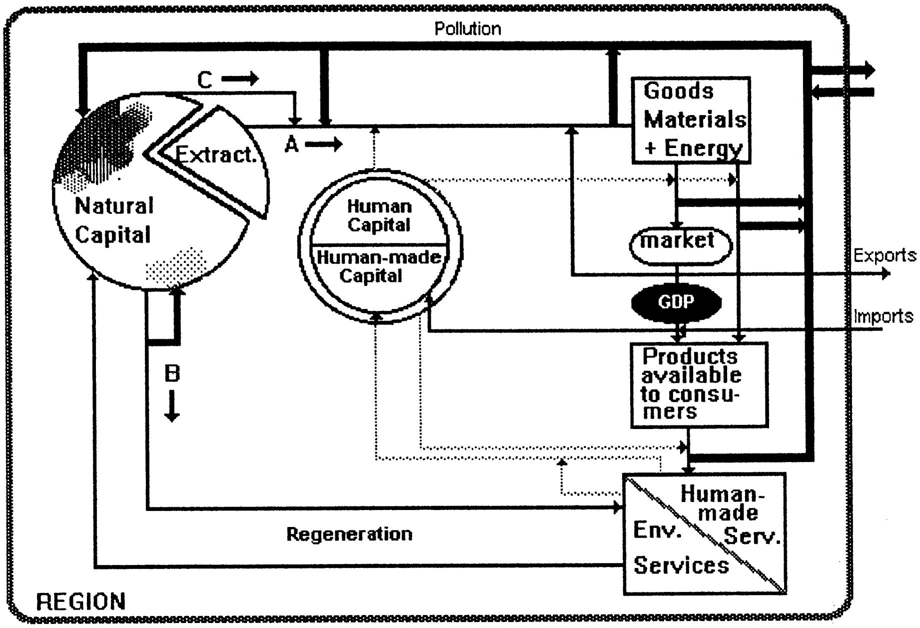

Fig. 2. The regional model relating quality of life and natural capital.

From a regional point of view, if the ability of natural capital to produce environmental services is impaired by the damage caused by extraction and pollution beyond its regeneration capacity, both production processes would be affected. Goods and energy can be imported, but many environmental services can only be produced locally. The boundaries of the region are permeable to some environmental services, but the region does not have control over this permeability. It is instead determined primarily by physical geography.

3.2. The conceptual framework of the regional model

In this section we will expand and define the concepts mentioned above, focusing on quality of life and natural capital, defining categories that will be used in research design and policy making. The main elements of the model that determine the quality of life of the region are presented in Fig. 3.

Natural capital contributes to the quality of life of a region in two complementary ways: first, by directly providing environmental services that cannot be imported, and second, by supplying the natural resources that, through a human controlled production process, become valuable to humans.[5] Environmental services also determine the ability of natural capital to regenerate itself. Ecosystems and other components of the regional natural capital produce environmental services

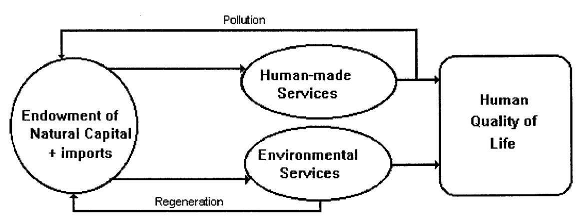

Fig. 3. Main elements of the regional model.

[5] The relation between human-made services and environmental services as components of the quality of life is a complex one that we do not address in this article. Only increases and decreases of human-made services and environmental services will be considered, not the way in which they complement each other. We also recognize that quality of life is determined in large part by social factors, which are not explicitly included in our model.

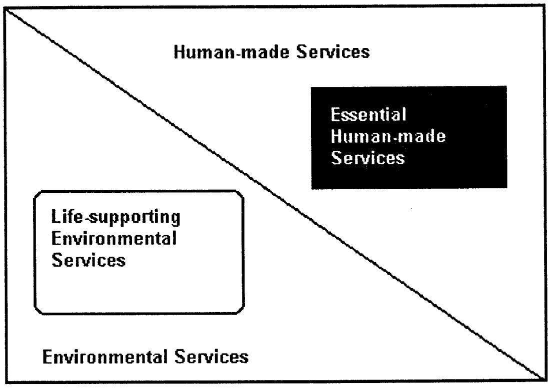

Fig. 4. Quality of life.

that provide life-support functions necessary for natural capital reproduction. Finally, the economic process generates waste, which alters natural capital and, as a consequence, the quality of life both in the short and long term.

3.2.1. *Quality of life*

The components of the quality of life of the region are presented in Fig. 4, and are defined subsequently.

3.2.1.1. Human made services. Human-made services are the services produced directly by people and those derived from goods during the consumption process. We distinguish human-made services into two socially determined categories:

- Essential services: those services that are necessary for human life. There are many approaches to define what is essential for a society. These approaches are related to different theories of well-being. These theories interpret well-being as a state of mind, a state of the world, as human capability, or as the satisfaction of underlying needs (Dodds, 1997). Our model leaves the determination of what is 'essential' to the society (or region) itself. For some regions weapons or cars can be considered essential, while to others these could be non-essential goods.
- Non-essential services: all other services produced.

3.2.1.2. Environmental services. Environmental services are functions that are provided by natural systems. They generally cannot be imported, and become part of the quality of life because they are important components of the surroundings in which humans live. They can be classified as:

- Life-supporting environmental services: these services are necessary for maintaining all kinds of life and for the regeneration of the natural systems. (i.e. the regeneration of soils, pollination of crops, maintenance of the atmosphere, waste assimilation, purification of water).
- These services make ecosystems dynamic self-regulating systems that maintain their essential structures in the face of exogenous shocks (homeostatic quality), that adapt to changes in their input and output environments (adaptiveness), and that are conducive to change in the species composition with time (succession) (Dryzek, 1992).[6]
- All other environmental services: these services affect quality of life but do not determine the survival or reproduction of the ecological system itself. They include recreational and aesthetic environmental services that are not provided with human intervention.

3.2.2. *Differentiating the stock of natural capital*

Natural capital is all that is not created by humans. It can be destroyed by human actions, and its reproduction can be influenced by human actions, such as in agriculture or plantation forests. It is the basis for the creation of most human-made capital and services. It also provides environmental services, including the necessary life support mechanisms for humans and other species, that allow for its own regeneration. All natural capital is not substitutable, however, so our model differentiates natural capital to provide a more precise framework for determining the quality of life of a region and the sustainability of

[6] This definition of life-supporting environmental services derives from a dynamic conception of ecosystems that are perpetually changing and undergoing disturbance (natural and human). Preserving nature 'untainted', or in a stable balance can therefore be, in many cases, counterproductive, and impair the self-organizing and self-recreating characteristics of ecosystems (Harte, 1995).

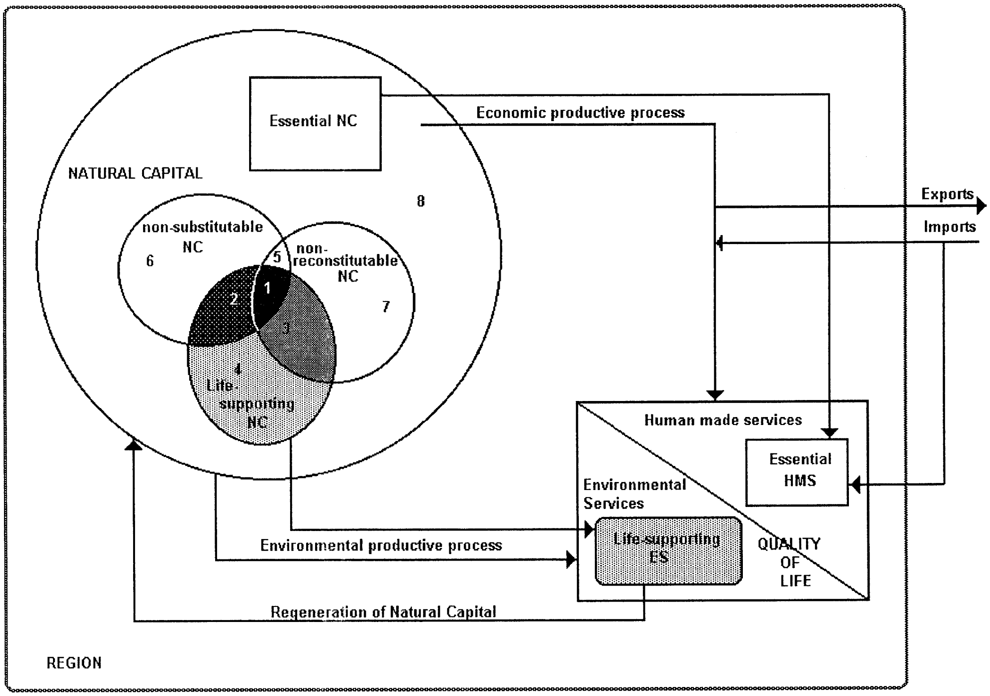

Fig. 5. Natural Capital Categories. Examples of natural capital in the different categories: (1) Rivers and riverine ecosystems that cannot be reconstituted, and provide non-substitutable support to life, (2) Artificial forests that provide environmental services necessary for life that cannot be provided with other kinds of capital, but could be reconstructed, (3) Riverine fishing areas, that could be substituted by non-life supporting natural capital or human-made capital (4) Wetlands, as purifiers of water, to some extent reconstitutable, and substitutable by artificial purifiers, (5) Landscape, sports and aesthetic natural capital (6) Gardens, agricultural land (7) Minerals (8) Artificial lakes, pasture land with low biodiversity.

its development path. Fig. 5 shows the natural capital categories of our model and how they are linked to the quality of life of the region.

Natural capital is classified in this model according to its ability to produce services in the following four categories:

- Essential natural capital: natural capital used by humans to produce services that are essential for human survival, such us food, shelter, clothing, as previously defined. The subset of natural capital determined by the need of essential human-made services can change because the population size changes, expectations change, or technology changes and allows the substitution of different kinds of natural capital to satisfy the same need. An example could be to replace the construction of hydroelectric plants by the production of more efficient electric bulbs. In this case the same service will be obtained with a different kind of natural capital. As noted above, the 'range of essentiality' should be determined by each region. How the region is defined (including its size) will make a difference in the social determination of what services are deemed to be essential, determining in turn the natural capital that is classified as essential. The size of the region will also determine the availability of natural capital to satisfy essential and other needs. A social problem may arise when there are overlapping or conflicting definitions of essential natural capital for different social groups contained in a region.[7]

[7] This problem may alter the quality of life of the regions, but it is not necessarily an environmental problem. It can become an environmental problem, however, if the conflict is resolved in a way that involves damaging actions to the environment, like some war actions or the destruction of crops.

- Life-supporting or critical natural capital (1, 2, 3, 4): the natural capital that produces life-supporting environmental services and is necessary for life reproduction. Examples are riverine ecosystems, wetlands, and forests that provide habitat for many species. This quality of natural capital is determined by nature.

Extraction is defined in this model as any action that destroys the integrity of an ecosystem.[8] This integrity is maintained by what has been previously defined as life-supporting environmental services, which are responsible for its self-regulation. Therefore any use of life-supporting natural capital that degrades the integrity of the natural capital is extraction since it will impair the ability of an ecosystem to maintain its ability to adapt and reproduce in the presence of exogenous stress. Use of the flow of life-supporting environmental services does not constitute extraction as long as the underlying service–producing natural capital stock–is not impaired in its ability to produce life-supporting environmental services.[9]

- Non-substitutable natural capital (1, 2, 5, 6): This kind of natural capital cannot be substituted by human-made capital. Examples are forests that regenerate soils, birds and insects that pollinate crops, and their habitats.
- Non-reconstitutable natural capital (1, 3, 5, 7): This kind of natural capital does not regenerate once it is destroyed, or it is too costly or impossible to reconstruct it artificially. It includes what economists call exhaustible resources, like minerals, and also complex ecosystems like rivers, native forests, or wetlands, that are impossible to create or recreate. In the case of complex ecosystems there is not only the difficulty and cost of putting them back together, but also the loss of information once they have been destroyed. In the case of minerals, the possibility of reconstitution is mostly a matter of cost: the amounts of energy needed to put them back in their original form is simply too high (Georgescu-Roegen, 1970).

What is non-reconstitutable and non-substitutable natural capital at a given moment is determined by the evolving responses of nature as well as the contingency imposed by past human actions. The categories presented in Fig. 5 are not sharply divided, have a range of variation, and are constantly changing by variations in the environment and new discoveries. This makes planning the use of natural capital a complex task that requires constant adjustment of these categories in order to maintain a sustainable state. This dynamic quality of the model has important implications for the design of institutional interventions to promote sustainability.[10]

Categories 1, 2, and 3, which result from the overlap of life-supporting or critical natural capital with non-substitutable and non-reconstitutable natural capital, are of special interest for conservation policy. Category 1 includes life-supporting natural capital that is not possible to substitute by other kinds of capital and cannot be reconstructed. Examples of this kind of natural capital are riverine ecosystems. Category 2 includes life-supporting natural capital that cannot be substituted by human-made capital, such as artificial forests. Category 3 is natural capital that is life-supporting and cannot be reconstituted, but could be substituted. An example could be wetlands in their role of purifying water.

3.2.3. Uses of natural capital

Fig. 5 represents an ideal utilization of natural capital. It discriminates the use of natural capital

[8] The concept of 'integrity' has been criticized as being too difficult to measure, however, due to the dynamic nature of ecological systems (Harte, 1995).

[9] An example of a use of life-supporting environmental services without extraction of the underlying life-supporting natural capital would be breathing, while an example of an extractive use of life-supporting natural capital would be diminishing the flow of a river so it cannot support some species. Pollution can also impair the ability of the underlying ecosystem (natural capital) to continue to provide those life-supporting environmental services, but we distinguish pollution from extraction here.

[10] In particular, it suggests that institutional interventions should explicitly adopt an 'adaptive management' approach, where policies and management initiatives are structured as experiments that are designed to collect information through monitoring that can resolve uncertainty about the impact of the interventions (Holling, 1995).

according to its ability to provide critical environmental services and essential human-made services. It would use essential natural capital only for the production of essential human-made services, and non-critical non-essential natural capital for the rest of the human-made services.

In a market economy the criteria to use natural capital is generally determined by the cost of extraction and/or accessibility of the needed resources. The cost of extraction, in turn, is influenced by institutional considerations such as the assignment of property rights and regulatory obligations for mitigating the environmental impacts of extraction. Natural capital is then extracted without explicit consideration of its ability to provide environmental services. This is at least in part due to institutional failures to discriminate between categories of natural capital. This practice is conducive to an erratic use of natural capital that can be unsustainable if it destroys critical natural capital.

3.3. Possible scenarios

Different interrelations among critical and essential natural capital define scenarios of different planning problems that require specific approaches.

3.3.1. Essential and critical natural capital do not overlap

Regions that are using critical natural capital, but could satisfy their essential human-made services with non-critical natural capital, could havee increases on both components of the quality of life if they do not take critical natural capital to satisfy non-essential needs. The problem of regional unsustainability can therefore be reduced with adequate environmental planning institutions that administer natural capital according to its ability to produce environmental services and human-made services. A systematic use of natural capital for sustainability would call for the complete avoidance of use of critical natural capital.

3.3.2. Essential and critical capital overlap

In regions where there is competition for the same natural capital that is critical and at the same time the basis for satisfying essential needs, the problem cannot always be solved by better administration. This could be the case for a region that needs wood as fuel, and can take it only from native forests that are considered critical for their function as habitat. Confronting these problems could require changes in the scale at which the problem is defined, changes in values, or changes in the objectives of investments and new technologies.

One approach could be to change the scale. If, for example, this problem arises in a small region, the model can be applied at a higher scale (i.e. redefining the 'region' by considering the problem at a different geographic and social scale) to see if the essential natural capital can be provided from non-critical natural capital sources at this scale. In this case (i.e. where overlap does not occur at the larger scale) the problem can be solved by transfers of non-critical and non-essential natural capital among the subregions, making the problem an administrative task. Increasing the scale is a good way to expand the sources potentially able to satisfy essential needs, but will probably complicate the process of decision making and reaching agreements by introducing demands on natural capital at two different levels. The definition of essential goods and services may also differ at these two scales.

If changing the scale is not possible, or does not solve the problem of having conflicts over the same natural capital (i.e. overlap of essential and critical natural capital still occurs), then some profound changes have to take place. Among the alternatives are:

- Changes in investments to provide the same services with human-made capital that does not utilize critical natural capital. Examples could be to replace hydroelectric power with more efficient bulbs, or solar power.
- Changes in technology that allow substitution of non-critical essential natural capital for critical essential natural capital. An example would be the development of new technologies to desalinate water (instead of diverting fresh water).
- Changes in technology that reduce the use of essential critical natural capital. These changes will reduce the degree of overlapping and therefore conflict.

- Changes in values and behavior that alter what is socially determined to be essential, determining a subset of natural capital that does not overlap with critical capital. An example would be dedicating more time for commuting, making it possible to ride a bike to work instead of a car that utilizes more non-reconstitutable natural capital.

If none of these changes are possible, and critical capital must be used, priorities for the use of critical natural capital can still be established: category 4 should be used first, then 3, then 2 and finally category 1 as a last resort. Current institutions rarely make these distinctions among different types of critical natural capital.[11]

4. The sustainability of regional development

The theoretical framework presented above answers the first question proposed at the beginning of this article: How does the use of natural capital affect the quality of life of a region? The theoretical framework shows, in general terms, that the long-term quality of life of a region that bases its development on the use of natural resources depends on what this region does with the different kinds of natural capital. In this section we develop a typology of regional development paths and evaluate them in terms of both their sustainability and their contributions to both human-made services (i.e. economic growth) and quality of life.

4.1. Conditions for sustainability

If a region uses the critical natural capital that is most essential for the production of environmental services and for its own regeneration, it will have a development path that diminishes the environmental services component of the quality of life in the long term. If it instead uses its natural capital in such a way that the ecosystems continue to produce environmental services, it will increase this component of the quality of life in the long term.

In a market economy, where an important part of the natural capital is in private hands, there are economic incentives to utilize natural capital to produce human-made services. These incentives do not exist for the production of environmental services, however, which are considered positive externalities of natural capital. This asymmetry in the incentives, together with the dominant social focus on economic growth (increases in human-made services), generally drive the system in only one direction: transferring natural capital from producing environmental services to producing human-made services.

Under these conditions the transfer of natural capital from producing environmental services to producing human-made services can be done in a sustainable way, without impairing the reproduction of natural capital and the production of environmental services, *only* if the economic system uses natural capital that is not critical. A necessary condition for sustainable development is, then, not to use critical natural capital. This is consistent with the concept of strong sustainability (Turner et al., 1994). It may not be a sufficient condition, however, if social and economic conditions are not sustained or are otherwise unsustainable by other social criteria. These social criteria may in turn be unrelated to ecological conditions.

To comply with this necessary condition, institutional interventions must be implemented to maintain the balance in the use of essential and natural capital and to strictly avoid the use of critical natural capital. This concept is similar to the idea of coevolution (Norgaard, 1994), in which social and environmental systems evolve and adapt to each other in a constantly changing balance. Our model places limits to the changes that can take place, however, which are deter-

[11] The US Endangered Species Act is an exception in that it prohibits the destruction of a non-reconstitutable, non-substitutable form of natural capital except when there is an inherent conflict between that prohibition and meeting some socially-determined essential human need. The Act is only invoked well after the integrity of ecosystems has already been compromised, however, leading to a threat of extinction that results in the listing of the species as threatened or endangered under the Act. The Act does not promote systematic prioritization as our model would. Social conflicts over protection of such critical, non-reconstitutable natural capital are therefore exacerbated.

Table 2
Paths of development–strong sustainability

Possible paths	Environmental services	Human-made services	Quality of life
1	Increases	Increases	Increases
2	Increases	Decreases	Increases
3	Increases	Decreases	Decreases
4	Increases	Decreases	Same
5	Increases	Same	Increases
6	Decreases	Increases	Increases
7	Decreases	Increases	Decreases
8	Decreases	Increases	Same
9	Decreases	Decreases	Decreases
10	Decreases	Same	Decreases
11	Same	Increases	Increases
12	Same	Decreases	Decreases
13	Same	Same	Same

mined by the non-reconstitutability and non-subtitutability of some life-supporting natural capital. The destruction of these kinds of natural capital can be conducive to the irreversible process of system breakdown, or 'distress syndrome' (Haskell et al., 1992). Our model therefore highlights that specific types of natural capital must be protected.

4.2. Alternative paths of development

The quality of life of a region is defined in traditional economics in terms of the human-made services available for consumption in that region. Development, or improvements in the quality of life, can therefore occur in only one way: by increasing the production of human-made services (economic growth). If the concept of quality of life of the region is expanded to include the availability of environmental services and human-made services, however, development is the evolution of the combination of human-made services and environmental services. This evolution determines the path of development a region takes. Table 2 shows the alternative development paths available to a region under the strong sustainability model (which differentiates natural capital less than our model) (Fig. 6).

Fig. 7 shows the cases presented in Table 2, with the directions development can take from a starting point (Q of L_0).

Some of these development paths with increments in the quality of life are sustainable (1, 2, 5, 11) according to the principle of strong sustainability because they increase or maintain the proportion of environmental services relative to human-made services. (Note that Table 2 indicates only the direction of change in the Quality of Life components without reference to the magnitude of change (and assuming a linear relationship between increases in ES or HMS and increases in Quality of Life) while Fig. 7 allows some quantification of the trade-offs between those components that may be associated with the change in one component. Because the components are incommensurate, however, we do not attempt to sum them into a single quantitative indicator. Fig. 7 shows how the Quality of Life for a region changes in both attributes for the 13 alternative paths of development presented by the strong sustainability model.)

According to our model, however, a region also has the option to avoid the use of life-supporting natural capital to produce human-made services. There are many more options to develop a region, therefore, when critical natural capital is differentiated from non-critical natural capital. Our model delineates 51 possible paths of development (compared with only 13 possible paths under the less-

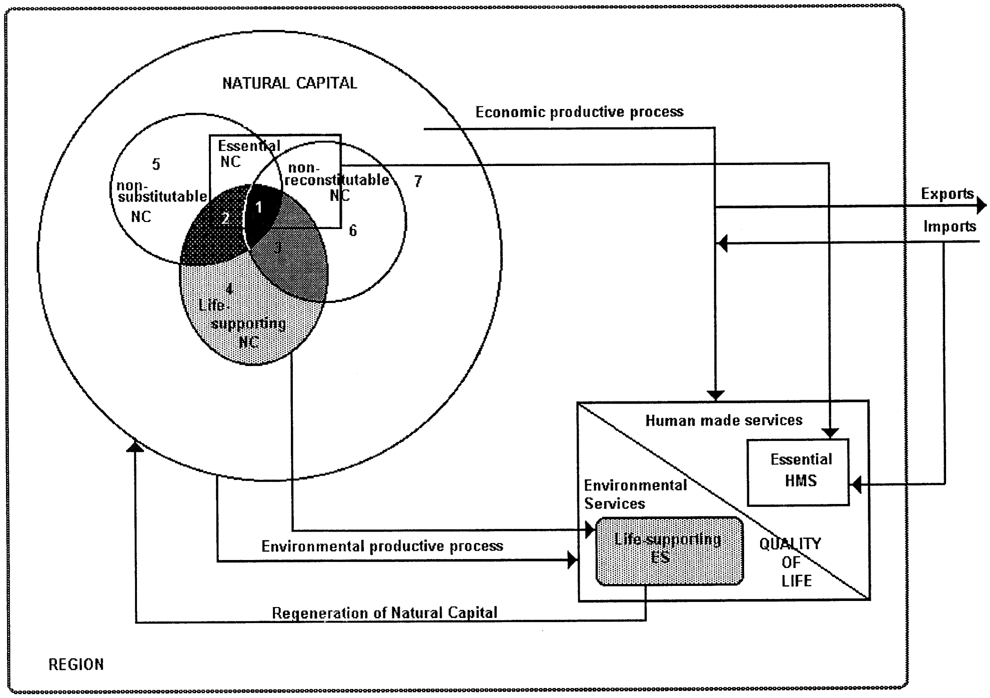

Fig. 6. Overlapping of essential and life-supporting Natural Capital.

differentiated strong sustainability criteria). These paths simply represent a more precise and differentiated application of the strong sustainability model, but we call this a strict sustainability approach for convenience. These paths are listed in Table 3.

Just as not all of the 51 paths are not sustainable, they do not all affect quality of life in the same way. Table 4 summarizes the paths in terms of both their sustainability and contribution to quality of life.

Note that economic growth is not the only option to increase the quality of life of a region. There are 14 paths for sustainable development, and from these paths only six are attained with economic growth (1, 15, 20, 34, 39, and 49). The rest increase the quality of life by increasing the production of either critical or non-critical environmental services, or both (2, 5, 16, 19, 23, 26, 40, and 43). All of the paths that constitute sustainable development are summarized graphically in Fig. 8 in terms of their contribution to economic growth (summarized here as Human

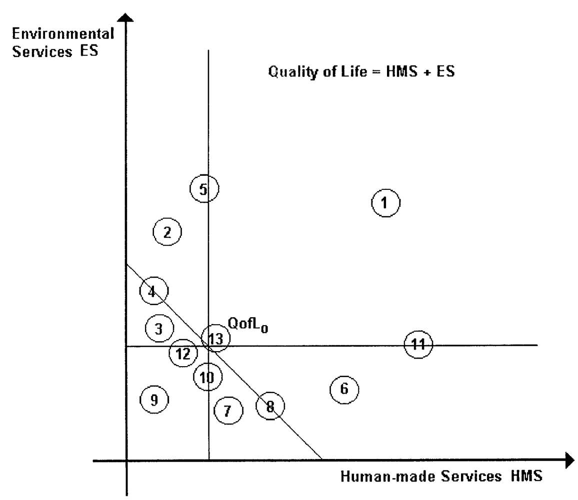

Fig. 7. Paths of development.

Table 3
Paths of development—strict sustainability

Possible paths	Non-critical environmental services	Critical environmental services	Human-made services	Resulting quality of life
1* (EG) [b]	Increases	Increases	Increases	Increases
2*[a]	Increases	Increases	Decreases	Increases
3[a]	Increases	Increases	Decreases	Decreases
4[a]	Increases	Increases	Decreases	Same
5* [a]	Increases	Increases	Same	Increases
6* (EG)	Increases	Decreases	Increases	Increases
7 (EG)	Increases	Decreases	Increases	Decreases
8 (EG)	Increases	Decreases	Increases	Same
9*	Increases	Decreases	Decreases	Increases
10	Increases	Decreases	Decreases	Decreases
11	Increases	Decreases	Decreases	Same
12*	Increases	Decreases	Same	Increases
13	Increases	Decreases	Same	Decreases
14	Increases	Decreases	Same	Same
15* (EG) [a]	Increases	Same	Increases	Increases
16*[a]	Increases	Same	Decreases	Increases
17[a]	Increases	Same	Decreases	Decreases
18[a]	Increases	Same	Decreases	Same
19*[a]	Increases	Same	Same	Increases
20* (EG) [a]	Decreases	Increases	Increases	Increases
21 (EG)[a]	Decreases	Increases	Increases	Decreases
22 (EG)[a]	Decreases	Increases	Increases	Same
23*	Decreases	Increases	Decreases	Increases
24[a]	Decreases	Increases	Decreases	Decreases
25[a]	Decreases	Increases	Decreases	Same
26*[a]	Decreases	Increases	Same	Increases
27[a]	Decreases	Increases	Same	Decreases
28[a]	Decreases	Increases	Same	Same
29 (EG)	Decreases	Decreases	Increases	Decreases
30* (EG)	Decreases	Decreases	Increases	Increases
31(EG)	Decreases	Decreases	Increases	Same
32	Decreases	Decreases	Decreases	Decreases
33	Decreases	Decreases	Same	Decreases
34* (EG) [a]	Decreases	Same	Increases	Increases
35 (EG)[a]	Decreases	Same	Increases	Decreases
36 (EG)[ab]	Decreases	Same	Increases	Same
37[a]	Decreases	Same	Decreases	Decreases
38[a]	Decreases	Same	Same	Decreases
39* (EG)	Same	Increases	Increases	Increases
40*	Same	Increases	Decreases	Increases
41[a]	Same	Increases	Decreases	Decreases
42[a]	Same	Increases	Decreases	Same
43*	Same	Increases	Same	Increases
44* (EG)	Same	Decreases	Increases	Increases
45 (EG)[b]	Same	Decreases	Increases	Decreases
46 (EG)	Same	Decreases	Increases	Same
47	Same	Decreases	Decreases	Decreases
48	Same	Decreases	Same	Decreases
49* (EG)	Same	Same	Increases	Increases
50[a]	Same	Same	Decreases	Decreases
51[a]	Same	Same	Same	Same

[a] Cells which contain footnote a, indicate sustainable paths of development (32 cases). Bold indicates sustainable paths with increments in the quality of life (14 cases).

[b] EG, indicates cases in which there is economic growth (19 cases).

* Indicates paths with increments in the quality of life (19 cases).

Made Services, or HMS, and environmental services, or ES, with a further distinction between critical and non-critical environmental services).[12]

Table 5 summarizes all 51 of the possible development paths in terms of their sustainability and contribution to economic growth. Note that economic growth is not always conducive to improvements in the quality of life of a region. Of the 19 paths that present economic growth, only eight increase the quality of life (1, 6, 15, 20, 30, 34, 39, and 49) and only six of these eight paths are sustainable (1, 15, 20, 34, 39, and 49). There are also nine cases that yield economic growth which is non-sustainable. Of these nine sustainable paths with economic growth, only three increase the quality of life (6, 30, and 44), while three maintain it (8, 31, and 46), and three diminish it (7, 29, and 45). Since these paths are unsustainable, the increases in quality of life of paths 6, 30, and 44 are only short-term options for meeting human needs.

4.3. Implications of the regional model

Our model demonstrates that there are very few paths of development that are truly sustainable. Moreover, it shows that many of the development paths that might be described as sustainable under the criteria summarized in section II are unsustainable under the more precise strong sustainability criteria (which we call 'strict sustainability') delineated by our model. This discrepancy has important implications for both the conclusions societies may reach about the sustainability of alternative development paths and the design of institutional interventions that may be necessary to achieve sustainability. Failing to differentiate natural capital in accordance with the model could lead to policies and strategies that may appear to be sustainable (under the less precise criteria presently in use in association with the 'strong sustainability' model), but which may nevertheless not be truly sustainable. Both evaluative criteria and policy instruments must therefore account for the distinctions made by the proposed model.

Societies do not now generally account for these distinctions. Sustainable development instead remains an ideal or a conceptual construct, although some communities and governments have attempted to delineate sustainability 'indicators' that would allow citizens to evaluate whether or not human activities are trending toward or away from sustainable practices. These indicators serve an important social function in translating the abstract notion of sustainability into practical, measurable conditions that have meaning for citizens and decision-makers. The indicators are generally not linked to an explicit model of ecological economics, however, which limits their usefulness for evaluating sustainability in a more systematic way. Moreover, policy instruments for achieving sustainable development are generally not conceived of or implemented with specific reference to a model of ecological economics that allows decision-makers to evaluate whether or not the selected institutional interventions will support

Table 4
Sustainability and quality of life[a]

Sustainability	Quality of life increases	Trade-off	Quality of life decreases
Sustainable	1, 2, 5, 15, 16, 19, 20, 23, 26, 34, 39, 40, 43, 49 = **14**	4, 18, 22, 25, 28, 36, 42, 51 = **8**	3, 17, 21, 24, 27, 35, 37, 38, 41, 50 = **10**
Non-sustainable	6, 9, 12, 30, 44 = **5**	8, 11, 14, 31, 46 = **5**	7, 10, 13, 29, 32, 33, 45, 47, 48 = **9**

[a] Development = changes in the quality of life (HMS and ES).

[12] Note that all of the paths shown as sustainable in Fig. 8 increase quality of Life, which is a stricter criteria than that used by the Brundtland Commission (World Commission on Environment and Development, 1987). The Brundtland Commission's criteria could increase HMS while decreasing ES, possibly decreasing quality of life.

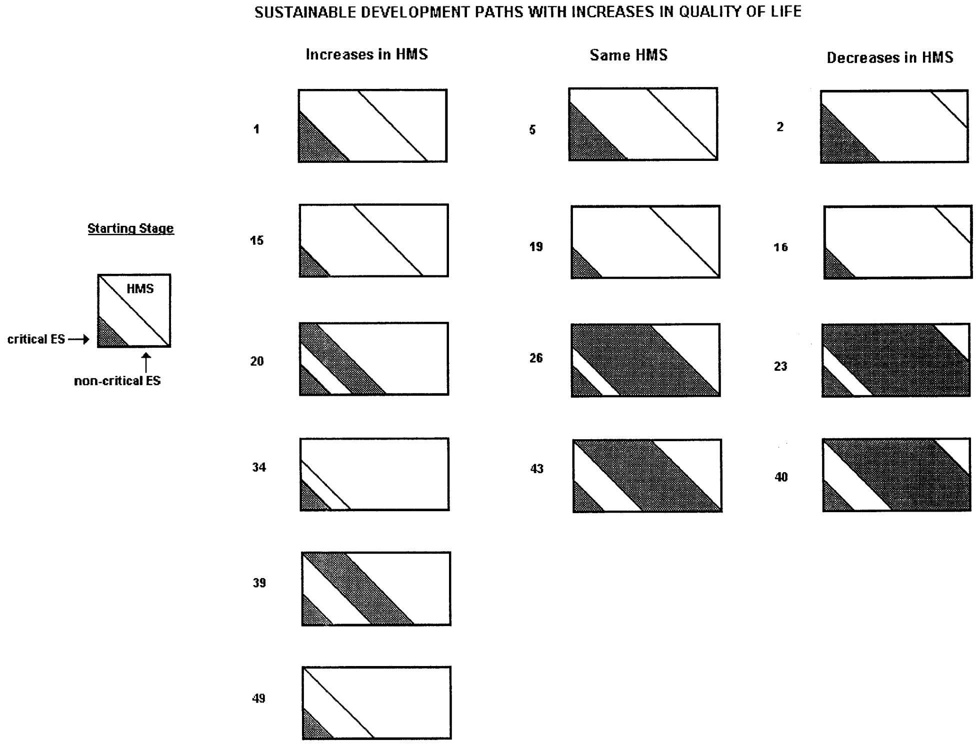

Fig. 8. Typology of sustainable development paths.

sustainability. New policies may therefore protect broad classes of natural capital unnecessarily while failing to protect the more important, but narrower, class of critical natural capital that provides life-supporting environmental services.

Our model suggests specific kinds of institutional interventions, however, that could improve both our capacity to evaluate the sustainability of alternative development paths and the likelihood that our economic and ecological systems will interact in a sustainable way. Regulatory systems could distinguish between different classes of natural capital based upon the categories in the model, for example, and priorities for the use of natural capital could be set in the order suggested by the model. At this time institutional frameworks generally fail to differentiate natural capital as finely as the model does, however, so it is difficult to test empirically the sustainability of development paths under a scenario that makes such fine distinctions. Our model nevertheless offers a basis for evaluating alternative paths of development, and it appears that very few of those paths meet strict sustainability criteria. It offers a more precise way to operationalize the concept of strong sustainabilty at a regional level.

Table 5
Sustainability and economic growth[a]

Sustainability	Economic growth	Stable economy	Economic de-growth
Sustainable	1, 15, 20, 21, 22, 34, 35, 36, 39, 49 = **10**	5, 19, 26, 27, 28, 38, 43, 51 = **8**	2, 3, 4, 16, 17, 18, 23, 24, 25, 37, 40, 41, 42, 50 = **14**
Non-sustainable	6, 7, 8, 29, 30, 31, 44, 45, 46 = **9**	12, 13, 14, 33, 48 = **5**	9, 10, 11, 32, 47 = **5**

[a] Development = economic growth (HMS only).

We are hopeful that it will also increase the likelihood of selecting a path that is sustainable.

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