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Biological integrity as a prerequisite for sustainable development: A bioeconomic perspective

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Biological Integrity as a Prerequisite for Sustainable Development: A Bioeconomic Perspective

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Abstract

The present paper argues that the operational conditions for Ecologically Sustainable Economic Development (ESED) may be described by a traditional welfare criterion: ESED refers to a process of economic processes that ensure the environmental prerequisites for an efficient evolution of intergenerational welfare. Under the premise of an unknown and unknowable structure of future generations' welfare, the only sustainable development trajectories are those that preserve the long-run potential for the efficiency of economic systems.

The paper focuses on the dependence of intergenerational efficiency on the biological-ecological infrastructure bequeathed to future generations. The efficiency criterion in an intergenerational context requires the preservation of the ecological necessities for future generations; in other words, the biological integrity of ecosystems should be preserved over the course of time. In order to make this idea operational, our study proposes the preservation of at least the Biologically Crucial Levels (BCL) of biological-ecological functions, environmental elements, and species. By preserving ecosystem health and biological integrity, BCLs bequeath to future generations the ecological infrastructure necessary to allow biological health, environmentally unconstrained shaping of preferences, and the enjoyment of welfare. BCLs represent an observable, measurable entity, which allows an operational design of policy for long-run sustainability, given our limited knowledge of the functioning of ecosystems. BCLs are an operational conservation concept inspired by contemporary trends in biological conservation.

Keywords: sustainable development, intergenerational welfare, intergenerational efficiency, biological integrity, biological sustainability, ecosystem health, biological conservation, safe minimum standards, critical natural capital, environmental rights, fair-sharing principle

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1. Environmental Rights for Future Generations?

Sustainable development embodies, by definition, many uncertainties. According to Bromley (1998): *"The analytical problem of sustainability has little to do with optimal utility levels over time. Rather, the essential problem of sustainability arises from the absence of knowledge about what those in the future would wish for us to do"*. Employing the same rationale, the present paper asserts that the real contribution of the concept of Ecologically Sustainable Economic Development (ESED) lies in its explicit consideration of the needs, preferences, and welfare of future generations. Equal importance should be attached to these attributes of future generations as to those of current generations in any evaluation of the economic process and development of an economy. Clearly, a realistic approach should recognize that our knowledge of the needs, preferences, and structure of the welfare of future generations is limited at best. Beyond certain preferences pertinent to basic biological needs, whatever preferences future generations might have are unknown and unknowable. Keeping this fundamental constraint in mind, it is imperative that the potential of generations to come be preserved. The 'environmental infrastructure' that permits future generations to enjoy biological health, to shape preferences, and pursue their fulfillment should be available to them; the environmental rights of future generations should be preserved and this preservation entails ensuring the potential for the efficient evolution of intergenerational welfare (Spash, 1993; Padilla, 2002; Bromley, 2004). Our approach focuses on the environmental infrastructure that determines the functioning of the ecosystems. The problem of the intergenerational allocation of (non-renewable) resources will not be treated here, as this has been sufficiently examined in the literature on intergenerational efficiency (Howarth, 1991b; Dasgupta and Heal, 1979; Pezzey, 1992; Solow, 1986; Solow, 1974; Georgescu-Roegen, 1979)

The present paper argues that the traditional economic methodology for evaluating alternative economic states offers an operational framework for investigating and planning ESED. Indeed, the Potential Pareto-Improvement criterion (the Pareto criterion as modified by Kaldor and Hicks to identify efficient welfare states) is appropriate for evaluating alternative paths of evolution of intergenerational welfare, and identifying the sustainable ones, provided that the welfare of all future generations is explicitly taken into account as being equal in importance to the welfare of present generations. Because the welfare of future generations is unknowable, the environmental prerequisites for the attainment of welfare should be preserved in the long run. *This condition ensures the attainment of Pareto-efficient*[1]*, Pareto-improving paths of evolution of intergenerational welfare, compared with paths* that arise when environmental prerequisites are not preserved. In a nutshell, we assert that sustainability ensures the potential for efficiency, when efficiency is assessed properly in the intergenerational context. In other words, we assert that sustainability requires the preservation of those environmental 'boundaries' within which intergenerational efficiency can be attained. It is worth mentioning that our approach is unable to rank different efficient evolutions of welfare that might arise once the appropriate infrastructure is preserved.

What we suggest in the present paper is an approach that is not constrained within limits imposed by reliance on prices, incomes and utility for future generations. Such variables are also unknown and indefinable (Bromley, 1998; Howarth, 2007). Under this inviolable constraint, we propose that environmental prospects and infrastructure should be maintained for the sake of future generations so that they will be able to benefit from good health; to determine their priorities; and to realize them. In essence, what we propose is the unconstrained preservation of 'environmental rights' to which future generations are entitled (Spash, 1993; Bromley, 2004).

The framework proposed here reconciles the requirement for 'inviolable rights of future generations' with the utilitarian concept of efficiency (Spash, 1993). We suggest that the preservation of 'inviolable rights' is the necessary condition for efficiency in intergenerational welfare. Our approach defines those environmental rights (but not necessarily comprising all existing environmental infrastructure) that should be bequeathed to future generations in order to achieve intergenerational efficiency. For these environmental rights, which should be preserved without compensatory frameworks, the 'inalienability rules' suggested by Bromley (1989) hold. Furthermore, our approach attempts to establish the appropriate biological spectrum within which the targets of environmental policy could be set to meet the criteria of effectiveness and democratic justification (Bromley, 2004).

The application of the Pareto-efficiency criterion to the definition of ESED gives interdisciplinary research an intriguing edge. However, traditional economic thought does not need to abandon its methodological basis in order to define ESED in operational terms. Economics – in collaboration with the biosciences – should determine what environmental infrastructure must be preserved in order to attain a

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[1] The term 'Pareto-efficient', used throughout the paper, indicates what is called the Potential Pareto-improved states of welfare. These can be simply denoted as efficient ones. The term 'Pareto-efficient' serves to remind the reader of the origins of the criterion of efficiency. The potential compensation principle and the implied moral philosophy are crucial for understanding the problem of comparing alternative welfare states. Furthermore, our dialogue with ecologists and biologists during the development of the present approach showed that they prefer to fully understand the roots of the measure of evaluation instead of being presented with the single and ideologically-loaded term 'efficiency'.

Pareto-efficient evolution of intergenerational welfare. This condition should be examined in a pragmatic framework "*by moving beyond the fiction of commodities and feeling, by abandoning models of the time machine and by recognizing that the presumed beneficence of spontaneous order is logically untenable*" (Bromley, 1998).

2. Efficiency as an Operational Criterion for Evaluating Intergenerational Welfare and Defining ESED

A prominent and innovative element in the quest for ESED should be the explicit and independent evaluation of the economic development of generations to come. Economic development is the path toward achieving welfare (Niccolucci et al., 2007). The concept of ESED suggests that today's economic decision making should include explicit consideration of the welfare of future generations.

In the literature, different assumptions on the welfare of future generations and ESED can be found (Neumayer, 2010; Rogers et al., 2007). The *weak sustainability* approach implicitly assumes that humans in the future will have preferences similar to those of current generations. The criterion of "non-declining per capita utility" as the basis for taking into account the welfare of future generations is in accordance with this assumption (Pezzey, 1992; Pearce and Atkinson, 1993). However, we assert that such a criterion lacks operational appeal because the utility of future generations is both unknown and unknowable. More important even, the preferences of future generations lie beyond the range of our experience or understanding. Admittedly, we are in a position to assume that human beings will continue to have to meet certain basic biological needs, but beyond that we do not have sufficient premises from which to extrapolate their preferences and judge their welfare.

The *strong sustainability* approach seems to implicitly accept that future human beings may have preferences different from those prevailing at present. In this light, natural capital should be bequeathed to future generations in order to facilitate their environmentally unconstrained shaping of preferences and pursuit of welfare. Several strong sustainability criteria have been proposed; some reflect partial considerations (Allen, 1980), while others lack operationality. Two criteria that seem to propose a clear context for action are: (i) the preservation of all existing natural capital (Daly, 1992, 2007; Constanza and Daly, 1992); and (ii) the preservation of the Critical Natural Capital (Ekins et al., 2003). We regard the preservation of all existing natural capital as simplistic and unnecessarily restrictive for the socio-economic process. At the same time, the Critical Natural Capital approach defines criticality according to the interests of current generations. In contrast, the present paper asserts that the needs, interests and welfare of future generations should be explicitly taken into account whenever economic processes are evaluated and current decisions are taken.

In this context, we propose (Pareto-) efficiency as the criterion for ESED. The efficiency criterion should be applied to the evaluation of alternative paths of intergenerational welfare. ESED is defined here as those patterns of socio-economic processes that entail a Pareto-efficient evolution of intergenerational welfare. Under the inevitable constraint that today's economic decision making cannot envisage the structure of welfare of future humans, the only rational action is to preserve the environmental prerequisites for welfare attainment by future generations. ESED is thus that a socio-economic process that does not impose environmental constraints on intergenerational welfare evolution. ESED preserves the environmental potential for 'efficient' intergenerational welfare evolution compared with the evolution that might arise if the environmental infrastructure is not preserved. In this manner, the welfare of all succeeding generations is taken into account in a systematic way.

The present article argues that ESED proposes a socio-economic process capable of preserving the environmental infrastructure and allowing future human beings to form preferences and to satisfy them in a way that results in Pareto-efficient intergenerational welfare evolution.

Evidently, within the context of intergenerational efficiency, the existing 'environmental infrastructure' may diminish, if that is the result of an increase in the current generation's welfare which is greater than the potential decrease of future generations' welfare. However, the reduction in environmental infrastructure has certain limits imposed by the criterion of Potential Pareto-improvement – the criterion of efficiency. The generations to come tend to infinity. Therefore, any irreversible reduction in the environmental potential for shaping preferences and enjoying welfare by future generations will result in an inefficient intergenerational evolution of welfare. The irreversible decay of environmental infrastructure results in welfare evolution that is inferior, under the efficiency criterion, to that arising when the environmental infrastructure is preserved for future generations without irreversible change.

The application of the Pareto-efficiency criterion to the evaluation of the intergenerational evolution of welfare permits a comparison that manages to avoid the knotty problem of interpersonal comparison and initial allocations. In the intergenerational context, the focus is on succeeding generations' prospects of attaining welfare, as well as on the trade-offs between these prospects and the welfare of current generations. Inevitably, the focus rests on the aggregate level of welfare, as the issue of intragenerational distribution raises formidable methodological problems.

To conclude, we suggest the following traditional economic criterion for the operational definition of ESED: it reflects a socio-economic process which preserves the inherited environmental infrastructure so that the potential for the efficient evolution of intergenerational welfare is strictly maintained. The question that still remains to be answered is how to define the environmental infrastructure that is to be bequeathed to future generations in order to ensure efficient welfare evolution.

3. Defining the Environmental Prerequisites for Efficient Intergenerational Welfare

For a systematic investigation of the 'environmental infrastructure' required for efficient welfare evolution, we adopt a simple model of the interrelationship between the environmental and the economic systems. This model has been proposed by Passet (1979), and is essentially based on systems analysis (Odum, 1971). Interestingly, biologists have also adopted similar considerations (Allen and Hoekstra, 1992).

The economic system is a subsystem of the human system, which is, in turn, a subsystem of the environmental one. The relationship between these systems applies to their material and energy aspects, and to the rules governing them: the material and energy elements of the economic system belong to the natural system, while the rules governing the elements and the processes taking place within the natural system inevitably apply to the material and energy elements of the economic system.

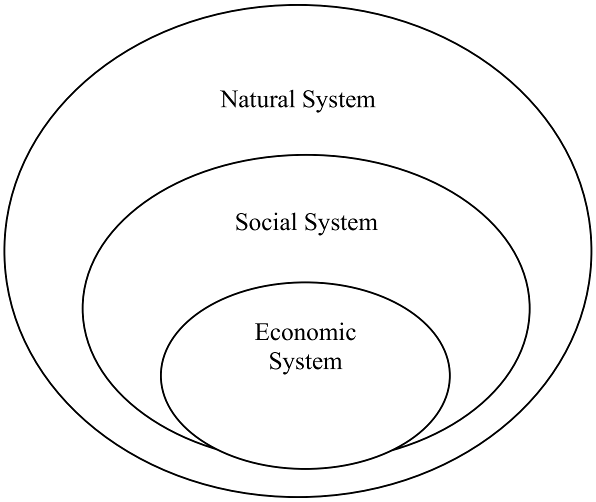

Figure 1: Relationship of economic, social and environmental systems

Based on Passet's model, we now aim to identify the environmental prerequisites for the attainment of efficient intergenerational welfare evolution.

I. Environmental Prerequisite A: Ensuring the 'healthy' biological functioning of mankind

Future generations should be afforded the chance of enjoying environmental conditions that ensure that the human race can continue to satisfy its biological needs.

The biologically-healthy functioning of human beings arises as the most fundamental biological need of the human race. This is the most important prerequisite for any other activity aiming at welfare. Healthy biological functioning is the absolute necessity that present and future generations have in common.

The biological status of the human race depends on the biological status of the planet's ecosystem (McMichael, 1993). The healthy functioning of the ecosystem provides the necessary biological conditions that enable human beings to enjoy biological health. The present paper asserts that the conservation of the biological functions, elements, and services that ensure the healthy biological status of the human race leads to Pareto-efficient intergenerational welfare paths when compared with paths resulting from non-conservation.

Safeguarding the healthy biological functioning of human beings emerges as the first prerequisite for the pursuit and attainment of any other kind of welfare. A biologically-ailing human race can hardly enjoy any other form of welfare. The inability to ensure healthy biological status, beyond some future generation, will become the concern of all human beings who come into existence thereafter, as they will be biologically weakened and barely able to enjoy other sources of welfare. If after a certain time in the future all humankind is afflicted with an unhealthy biological status, then effectively another biological race will have arisen. It will bear a resemblance to humankind but it will be so biologically degenerated that, in essence, it will not be humankind as we know it now, but a new biological species with human-like but inferior biological traits.

A severely unhealthy biological status could substantially disrupt a particular individual's welfare. But even so, for some individuals, an unhealthy biological status could still leave sufficient room for them to enjoy other sources of welfare. However, the situation changes dramatically when considering serious biological decay that affects every member of all the generations to come after a future time. In that case, the aggregate welfare of each generation beyond that point becomes substantially reduced. To assume positive welfare for degenerate human beings, at the aggregate level, it is necessary to envisage another biological race with impoverished biological properties and potential compared with the human race as we know it.

In this context, we assert that when the healthy biological status of human beings is ensured, then socio-economic welfare tends to move to zero at the aggregate level. Let us give a simple analytical presentation of the argument.

The aggregate welfare w_i of generation i can be expressed as a function of economic welfare Y_i and welfare B_i arising from a healthy biological status:

$w_i = f(B_i, Y_i)$.

The requirement for $w_i = f(B_i, Y_i) > 0$ is that $B_i > 0$. If healthy biological status is not ensured for generation i so that B_i tends to 0, then w_i also tends to 0.

We are now able to compare two alternative evolutions of intergenerational welfare. In the evolution $u_1, u_2 \ldots\ldots u_n$, all generations to come are assured of a healthy biological status. On the other hand, in the evolution $w_1, w_2 \ldots\ldots\ldots\ldots w_n$, the healthy biological functioning of the human race is seriously disrupted after generation j by intensified environmental decay: this implies that w_j tends to 0, and the same holds true for all subsequent generations. We may now estimate the aggregate welfare of the two indicative evolutions in order to compare them in efficiency terms. Let

$$U_n = \sum_{t=1}^{n} u_i = u_1 + u_2 + \ldots\ldots\ldots + u_n;$$

$$W_n = \sum_{t=1}^{n} w_i = w_1 + w_2 + \ldots\ldots\ldots + u_n.$$

Evidently, $U_n > W_n$, as n becomes large, so that the former sequence of intergenerational evolution of welfare is, according to the Potential Pareto-improvement criterion, superior to the latter. The U_i sequence of successive generations' welfare is more efficient than W_i.

II. Environmental Prerequisite B: Preserving the environmental infrastructure for the unconstrained shaping of preferences by future generations

The second environmental prerequisite for efficient welfare evolution is to preserve the environmental potential for the unconstrained formation of preferences in future generations. Forming preferences is a social process that depends on social, institutional, technical, and cultural settings. In social evolution, one may identify preferences that depend directly or indirectly on the natural environment. The natural environment offers a vast infrastructure related to the preferences of individuals (Kallis and Norgaard, 2010)

The properties of the earth's ecosystem define in the present – and will determine in the future – the prospects for shaping preferences and pursuing their satisfaction. It is also evident that a significant number of preferences in the future will depend on the natural environment only to a limited extent, if at all. Nevertheless, as the preferences of future generations are unknown and unknowable, the insistence on ESED makes it imperative to safeguard future generations' rights to the environmental infrastructure that allows the unconstrained shaping of preferences. This condition is extremely crucial today as the impact of socio-economic activities has subjected the biosphere[2] to substantial modifications of the composition, structure, and function of its ecosystems. The earth's ecosystems are on the verge of irreversible degradation, if not already deeply entrenched in it. Climate change, biodiversity

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[2] Biosphere is: "the earth's living system, which occupies a thin layer from the deepest oceans to the top of the highest mountains… and the atmosphere, the thin envelope of gases that encircles the planet" (Chu and Karr, 2001).

losses, desertification, and the pollution of water resources are but a few of the symptoms. If the current trend in environmental impacts continues unabated, the environmental infrastructure available to future generations for shaping preferences will be irreversibly depleted. According to the Potential Pareto-improvement criterion, such a development can only lead to inferior intergenerational welfare sequences when compared with those that would stem from preserving an environmental infrastructure capable of supporting the unconstrained shaping of preferences for generations to come.

Let us now compare two indicative intergenerational sequences of welfare in efficiency terms by estimating the aggregate welfare levels:

$$U_n = \sum_{i=1}^{n} u_i = u_1 + u_2 + \cdots u_z + \cdots u_n,$$

where U_n represents the aggregate of an intergenerational welfare evolution in which all future generations are freely able to form preferences that depend on the environment, and to pursue their fulfillment effectively. In contrast, in the evolution:

$$W_n = \sum_{i=1}^{n} w_i = w_1 + w_2 + \cdots w_z + \cdots w_n,$$

the environmental status after generation z does not permit the unconstrained shaping of preferences that depend on the environment, where n denotes a sufficiently distant period.

With future preferences being unknowable today, it is very possible that after generation z, $w_i < u_i$. The potential of generations after z to attain welfare arising directly or indirectly from the environment are diminished, since in the sequence W_i the environmental infrastructure for shaping preferences has been substantially reduced. The generations to come after z tend towards infinity, hence $U_n > W_n$. The probability of this outcome increases with the probability of future generations desiring preferences dependent on the environment. Given the uncertainty surrounding the preferences of future generations, it is essential that the environmental infrastructure be preserved in order to ensure Pareto-efficient welfare evolutions.

III. Environmental Prerequisite C: Providing the economic process with natural inputs

The third environmental prerequisite for the attainment of welfare is the input of a sufficient quantity of natural resources into the economic process. This is a provision that should and must be ensured for the generations to come according to the requirement of ESED. This provision has been substantially analysed in the area of resource and growth economics (Van den Bergh, 2011).

This issue is extremely complex, as it involves several crucial aspects. What level of production should be ‘supported’ with natural resources? Which technological advances will be linked to the productivity of natural inputs? What will the global population be when future generations come along? Will new resources be discovered? Will reuse of ‘waste’ products of today’s built capital circumvent shortages of natural capital? These are but a few indicative questions that are likely to remain unanswered today, while the current generation takes the relevant economic decisions.

These questions also define the area in which a heated debate between two opposite approaches of economic thought has taken place. Georgescu-Roegen’s and Solow’s considerations are the most typical examples of the distinct approaches with regard to the absolute scarcity of natural inputs and its constraint on the economic process (Solow, 1974; Georgescu-Roegen, 1979). They represent two distinct schools of economic thought with different assumptions about, and attitudes towards, the issues mentioned above.

For the time being, we can safely accept the premise that economic process requires net inputs of natural resources, and will continue to do so for the foreseeable future (Kaufmann, 1992). Based on this premise, the present paper attempts to identify those management conditions according to which the intergenerational allocation of natural resources ensures the potential for efficient intergenerational welfare. Such conditions can only be defined with regard to renewable exhaustible resources. With regard to renewable inexhaustible resources no such stipulations are necessary, because current use has no effect on their potential for future use.

IIIa. Renewable resources

If the use of exhaustible resources is held below their regeneration rate, then the potential for intergenerational welfare evolution is Pareto-efficient compared with the potential that results when this management rule does not apply.

Evidently, different stocks have different regeneration rates. Our approach cannot rank them. The proposed management rule prescribes that the yield should not persistently exceed the regeneration rate, so that the resource can be made available to future generations. This availability entails efficient potential for the intergenerational welfare. Let $u_i > 0$ denote the welfare arising from the use of a given renewable exhaustible resource. If the proposed management rule applies, then the resource will be available to all future generations. The aggregate of potential intergenerational welfare arising from the production potential from the resource concerned is:

$$U_n = \sum u_i = u_1 + u_2 + \ldots. + u_z \ldots\ldots\ldots + u_n,$$

where n stands for an extremely distant time in the future.

In contrast, if a pattern of use that exploits the resource at a future time z prevails, then the generations after generation z are deprived of the relevant production possibilities. In this case, the welfare potentials w_i, are: $w_i > 0$ from 1 to z but $w_i = 0$ thereafter. Evidently, $U_n > W_n$; U_n is more efficient than W_n . According to the Potential Pareto-improvement criterion, the U_i sequence is therefore superior to W_i.

It is clear that the sequence u_i may take several particular forms that represent the welfare potentials arising from different patterns in the stocks and their respective yields. We are unable to propose an unambiguous criterion on which to base a ranking of these alternatives and to define the optimum or the most efficient ones. Nevertheless, all these alternatives lead to welfare evolutions that are more efficient than those of type w_j in which the resource is depleted in a future period.

It is evident that, in the production process, an exhaustible resource can be substituted by other resources or man-made elements. This potential for substitutions makes the comparison between U_n and W_n inconsequential. Nevertheless, the proposed evaluation framework is appropriate if one strictly assumes that future generations should have access to all existing renewable exhaustible resources. This accessibility ensures the rights of future generations to enjoy production prospects that depend on all currently available renewable exhaustible resources. To ensure the rights of future generations means providing them with freedom of action in the production spectrum that is at least equal to that available to the current generation.

As far as renewable resources are concerned, the rights of future generations to unfettered and multidimensional production possibilities, at least equal to today's, make the u_i type evolutions superior to the w_j type. The right of future generations to pursue the production of goods depending on inputs of exhaustible resources renders the u_i sequence superior, in terms of efficiency, to w_i.

IIIb. Non-renewable resources

The use of non-renewable resources in the production process and their allocation among generations is a highly intricate and complex issue. Current use deprives future generations of a certain amount of resources. Similarly, preserving resources for future use results in constraints on their current use.

There has always been a tacit and subtle competition between generations vying for access to non-renewable resources. In this context, the criterion of efficiency has little capacity to rank alternatives in the intergenerational allocation of non-renewable resources. Efficiency, within the neoclassical synthesis, is related to discounting future utilities. The pursuit of efficiency inevitably leads to intergenerational allocations favouring current and near generations (Dasgupta and Heal, 1979; Pezzey 1992). In fact, efficient allocations indicate the 'optimum' depletion paths. These paths ignore the needs of future generations for non-renewable resources. In order to overcome this fundamental, possibly inevitable flaw, ‘compensation modes’ are envisaged. Compensation modes may take the form of technology, capital, substitution potential or other endowments (Solow, 1986). Compensation schemes are also proposed outside the neoclassical school (Bromley, 1989; Padilla, 2002). On the other hand, any attempt to allocate non-renewables evenly among generations results in the paradoxical allocation of an amount tending to zero in every generation (Georgescu-Roegen, 1979, p.102). Admittedly, neither strict efficiency nor strict equity can rule the allocation of non-renewable resources. Probably the solution should be sought in a return to the very origins of economic science. ‘Economy’ in ancient Greece originally defined a state of using something prudently. To ‘economize’ implied saving and avoiding waste. Tenets for the allocation of non-renewables can perhaps be inspired by ‘economy’ in their use, i.e. by economizing on them.

Similar conclusions – that efficiency criteria cannot alone govern the intergenerational allocation of non-renewable resources – have been reached by Howarth (1991a, 1991b, 2007), Howarth and Norgaard (1990), and Georgescu-Roegen (1976). Characteristically, Howarth states that “*A desirable distribution of welfare between present and future generations requires that the asset transfer regime be chosen according to a social welfare function or explicit distributional criterion; economic efficiency, per se, is inefficient to ensure social optimality*” (Howarth, 1991b). In emphasizing the inappropriateness of standard economic theory for prescribing criteria, Georgescu-Roegen states: “*This is why whenever we may try to prescribe a quantitative policy for the economy of resources we can only play the tune by ear. Besides, instead of basing our recommendations on the ultra familiar principle of maximizing ‘utility’ we should try to minimize future regrets*” (Georgescu-Roegen, 1979).

4. Biological Sustainability: Lessons from Biology for ESED

The maintenance of a healthy biological functioning of the human race, and the avoidance of irreversible deterioration in the ecological status of the ecosystems that preserve the unconstrained shaping of preferences, can only be ensured through the healthy evolution of the biosphere. This condition has attracted the interest of classical preservationists (Muir, 1916), and lies at the core of contemporary preservationism (Noss, 1995). The biological-ecological integrity of the earth’s ecosystem necessitates healthy ecological functioning and preserves the two fundamental prerequisites for efficient intergenerational welfare evolution (Karr, 1993):

- Biological integrity provides the 'biological infrastructure' for the healthy existence and evolution of humankind which is a *bona fide* biological species, albeit *sui generis*.
- Biological integrity bequeaths to future generations the freedom to shape environmentally-based preferences.

Biological-ecological integrity implies the "*wholeness of a living system, including the capacity to sustain the full range of organisms and process having evolved in a region*" (Chu and Karr 2001). The key concepts behind biological integrity are the ecosystem's organisms and process. The quantitatively and qualitatively adequate presence of organisms and the preservation of the ecological processes lead to the proper functioning and evolution of ecosystems. Under these conditions, ecosystems enjoy a healthy state and evolution or, in other words, "*a flourishing condition, well being, capacity of self renewal*" (Chu and Karr, 2001).

Degradation of the biosphere and its ecosystems is caused mainly by the environmental impacts of human activities. The intensified impacts of human action result in biotic impoverishment that indicates the fundamental degradation of ecosystems. Biotic impoverishment is the systematic reduction in the capacity of the biosphere to support the forms of life in the earth's system (Chu and Karr, 2001)

Absolute biological-ecological integrity describes a state devoid of human impacts and thus defines a reference condition for evaluating the status of an ecosystem in ecological terms (Karr, 1991; Barbour et al., 2000). Angermeier and Karr (1994) define ecological integrity as the historic species composition and structure of ecosystems. In the majority of ecosystems, human societies exist and act. Human presence and economic action will necessarily compromise the ecosystem's biological-ecological integrity. Thus the status of these ecosystems cannot be described as being similar to that of the reference condition of biological integrity. Under these conditions, the realistic target for ensuring the proper functioning and evolution of ecosystems in the presence of human impacts is to maintain at least that minimum level of biological integrity that ensures the fundamental properties of ecosystems. Even in a state where impacts and degradation exist together, ecosystems can still preserve their inherent potential, their renewal processes, and their capacity for self-repair when perturbed (Karr, 1991; Rapport, 1995). Such a state of ecosystems is defined as 'ecosystem health' (Callicott and Mumford, 1997).

Preserving at least the minimum necessary level of biological-ecological integrity ensures the healthy ecological functioning and evolution of ecosystems, and hence the potential for the healthy biological existence of the human race and of the environmental infrastructure for the unconstrained shaping of preferences for future generations. This may be defined as *'biological sustainability'*. Similarly, Callicott and Mumford (1997) define ecological sustainability as a conservation concept that describes the maintenance, in the same place at the same time, of two integrated things: culturally-selected economic activities, and ecosystem health. Biological-ecological sustainability is a first-order, necessary condition for ESED.

The present paper attempts to trace the operational conditions of Biological Sustainability from the point of view of economic science, and hence to offer operational concepts that support the evaluation of economic processes. In fact, we trace the policy and decision-making relevance of Biological Sustainability, aiming to identify concepts and variables deriving from biology and ecology that can be used for economic evaluation and design. To this end, contributions from biology, ecology, and other natural sciences will be of great importance because the approach to be outlined will be essentially a bioeconomic one.

In this realistic context, the present study aims to determine the operational conditions for Biological Sustainability. The definition of the operational conditions for the ecologically- and biologically-healthy functioning of the earth's ecosystem, and hence for Biological Sustainability, is a very complex issue that is further clouded by limited knowledge of ecosystems. Indeed, despite rapid progress in the sciences of ecology and biology, their contribution to the decision-making progress is very limited in operational terms.

An operational bioeconomic approach should adopt existing knowledge of biology and ecology and then determine operational principles based on avoiding risks that may jeopardize the healthy functioning of the biosphere. Risks could be defined as those trajectories which, after leading to grave and irreversible deterioration, may result in the disturbance of the minimum level of biological and ecological integrity and hence of biological and ecological health.

Admittedly, the biosciences assume that there are important ecological processes that determine the proper functioning of ecosystem wholeness (Callicott and Mumford, 1997). These functions are simply the key processes of an ecosystem in a healthy state. They could be characterized as crucial ecosystem functions that depend on the presence of certain environmental elements and biological species (Krebs, 1994). These elements and species play a central role in biological functions, and are known as 'key species' or 'keystone species' (Krebs, 1994; Batabyal, 2002). Key species are crucial for biological health and integrity, and hence for biological sustainability.

Extending this rationale so as to cover the needs for environmental systems management from the point of view of economists and decision makers, one may identify a number of environmental elements and biological species that determine the state of ecosystem functioning.

The crucial environmental functions depend on crucial biological and environmental elements and biological species (key species). As long as these elements and species are preserved within certain limits of quality and quantity, the corresponding environmental functions perform well and ensure at least the very minimum of the ecosystems' biological integrity, and hence of biological health. Hence, biological sustainability is preserved. The required levels of the crucial biological-environmental elements are a managerial concept and could be characterized as biologically and ecologically crucial levels. The concept of Biologically Crucial Levels has been adopted by ecology and biology as 'ecological–biological thresholds' (Huggett, 2005). "*An ecological threshold is the point at which there is an abrupt change in an ecosystem………..or where small changes in an environmental driver produce large responses in the ecosystems"* (Groffman et al., 2006).

To summarize our argument, the preservation of the critical levels of the crucial biological species and environmental elements emerges as the operational condition that maintains ecological-biological health, at least the minimum level of biological integrity, and hence Biological Sustainability. Essentially, we propose a sequence of necessary requirements entailing observable and measurable entities that are the 'biologically crucial levels' (see Figure 2). The result is the creation of an operational framework for preserving the healthy functioning of ecosystems.

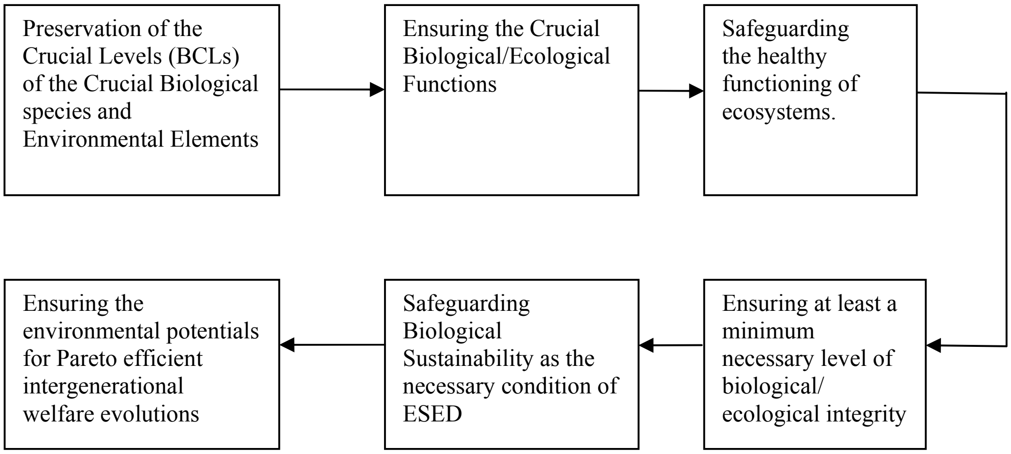

Figure 2: An operational sequence for preserving ecological health and ensuring biological sustainability

The rationale for defining BCLs could be extended to cover chemical and physical substances within ecosystems. Analysing and evaluating the state and functioning of ecosystems through the chemical and physical substances on which they depend has long been a tradition in environmental management. Even though describing and assessing an ecosystem's state and functioning in this way leaves much to be desired, its physical and chemical characteristics do provide a useful store of knowledge and information. Their analysis can make a positive contribution to the effective management of ecosystems especially in cases where knowledge of the biological and ecological characteristics is insufficient. Chemical and physical parameters should remain within levels that ensure the proper functioning of the ecosystems. These levels are analogous to the BCLs of biological species and characteristics.

In this context, pollutants – a specific category of chemical/physical elements – should be managed appropriately. Once the level of a pollutant has overwhelmed the assimilation capacity of the ecosystem, further accumulation will result in severe disruption of ecological processes, crucial biological species, and environmental elements. In order to ensure biological integrity and hence the healthy state of ecosystems, the level of each pollutant should be kept below its crucial level.

The proposal for preserving the crucial levels with regard to the crucial bio-species, environmental elements, chemical and physical substances and pollutants will inevitably reflect our limited knowledge of the functioning of ecosystems. However, in view of this uncertainty, preserving the Biologically Crucial Levels offers an operational action plan that adopts a risk-averse rationale.

5. The Relation of BCLs to Other Bioeconomic Approaches and Criteria

The approach that the present paper proposes for the preservation of Biologically Crucial Levels of the crucial species, environmental elements, and physical-chemical components as a condition for healthy functioning, biological integrity and hence biological sustainability, bears clear similarities to other approaches to Ecological Economics and Bioeconomics. A sample of such perspectives will now be discussed briefly.

5.1 The Critical Natural Capital Approach

The approach of Critical Natural Capital (CNC) emerges as the approach which is most akin to the BCL approach. CNC has been defined as the "*natural capital which is responsible for important environmental functions and which cannot be substituted in the provision of these functions by manufactured capital*", as well as the "*critical* *natural capital the maintenance of which is essential for environmental sustainability*" (Ekins et al., 2003). These two revealing definitions serve to identify two important differences between the BCL and CNC approaches.

Firstly, in the CNC approach the critical natural capital is defined as if there are no man-made substitutes. In contrast, within the framework of the BCL approach, the crucial functions, crucial species, elements, and their corresponding biologically crucial levels are defined according to their importance to biological health and integrity, regardless of whether man-made substitutes exist or not. The criteria for defining BCLs are purely biological-ecological and are prescribed by the biosciences.

In the intergenerational context, this difference becomes fundamental. According to the BCL approach the crucial biological species and environmental elements and, through them, biological health and integrity are the legacy of the present to future generations so that the latter may be free to shape environmentally-based preferences, and to enjoy a biologically healthy status. The rationale is simple: firstly, future generations may not be satisfied with man-made substitutes which could reduce their potentials for forming preferences and satisfying wants under the conditions that may arise and prevail in the future; secondly, for the human race there is no adequately substitute for biological health and at least a minimum level of biological integrity. Indeed, ecologists and biologists strictly reject the possibility of substituting important ecological processes and functions with artificial substitutes (Ehrlich, 1989; Kaufmann, 1995).

The second fundamental difference between the BCL and CNC approaches is that the latter adopts a broader spectrum of criteria in order to define the critical natural capital: "*Determination of criticality thus depends on ecological as well as economic, political, and social criteria*" (MacDonald et al., 1999); "*critical levels depend not only on ecological standards, but are also related to standard of living and relative affluences*" (De Groot et al., 2003). In effect, the CNC approach adopts criteria of criticality that reflect biological, political and economic conditions. In contrast, the BCL approach defines Biologically Crucial Levels on the basis of purely biological-ecological criteria.

As a result, the Critical Natural Capital approach embraces a broader thematic spectrum in contrast to that of the Biologically Crucial Levels of crucial species and elements. The BCL approach concentrates on the more limited environmental elements that are necessary for biological health and integrity. They are defined as 'crucial', irrespective of the possible existence of anthropogenic substitutes.

5.2 The Key Species Approach

The 'key species' approach bears striking similarities to the BCL approach and has its origins in ecology and biology. Key species are defined so that "*A role may be* *occupied by a single species and the presence of that role may be critical to the community. Such important species are called keystone species because their activities determine community structure*" (Krebs, 1999). Key species correspond to the critical species or elements of the BCL approach. Key species are those species that determine the healthy functioning of ecosystems (Batabyal, 2002). The BCL approach assumes that, apart from key species, the healthy functioning may also depend on crucial environmental elements such as physical and chemical substances, and pollutants.

Furthermore, the BCLs of key species may differ from the 'minimum viable populations' that ensure the avoidance of the species' extinction, a decisive management concept within the 'key species' framework. The biologically crucial levels may be set considerably higher than the minimum viable population.

5.3 The Safe Minimum Standards Criterion

The Safe Minimum Standards (SMS) criterion (Bishop, 1978; Ciriacy-Wantrup, 1952), also bears considerable similarities to the BCL approach. Safe minimum standards should be preserved on condition that their preservation does not prove too restrictive for economic growth. In other words, this approach permits the violation of the minimum standards should their protection be found to require relatively high costs (foregone benefits). In contrast, the BCL approach demands that crucial levels be preserved regardless of the costs involved. In the context of BCL, beyond the traditional cost-benefit economic constraint, economic processes should also be judged by an ecological constraint – biological health of ecosystems – and the associated norm, the preservation of BCLs.

Both approaches involve economic variables. The decisive consideration of the BCL approach is that the preservation of BCLs ensures *efficient* intergenerational evolution of welfare, once the welfare potentials of all future generations have been taken into account. On the other hand, the SMS criterion gives a weighting to the short-run economic costs which are related to the welfare for current generations

5.4 The Fair-Sharing Principle

The Fair-Sharing Principle (FSP) was proposed by Howarth as an operational sustainability criterion. According to the FSP: "*Each member of present and future society is entitled to share fairly in the benefits derived from environmental resources. Specific stocks of environmental resources should not be depleted without rendering just compensation to members of future generations*" (Howarth, 2007). This differs substantially from our approach. FSP permits the decay of environmental infrastructure bequeathed to future generations. The condition for such decay is the actual compensation to future generations. In our opinion, such a compensation scheme violates the core of Howarth's rationale: that the preferences of future generations cannot be known today. In this context, Howarth's approach is appropriate for governing the use of non-renewable resources. Their current use should provide a compensatory benefit to future generations, beyond the direct benefits to the current individuals.

However, FSP is risky if applied to the management of the infrastructure necessary to ensure the biological health status and evolution of humankind, as well as the environmentally-unconstrained shaping of preferences. Howarth's approach would probably be more appropriate for managing environmental systems when they are well above the biologically crucial levels that determine the minimum requirement for ecosystem health. The FSP approach is certainly unsuitable for managing ecological health and biological sustainability.

6. Conclusions

The present article maintains that the requirement of 'Ecologically Sustainable Economic Development' (ESED) can be defined sufficiently well so as to enable the establishment of an operational framework within the rationale of traditional economic theory. To this purpose, the present paper asserts that sustainable development requires the preservation of environmental and ecological conditions so that welfare may be maximized in the long run. The phrase 'in the long run' should extend to cover all future generations, and their welfare should be taken directly into account. As an appropriate criterion for evaluating the welfare of all generations, we have suggested the classic economic criterion of efficiency. In the context of sustainable development, it recommends the preservation of the potential for maximizing the aggregate welfare of all generations to come. Any path of intergenerational welfare evolution over time must meet this criterion in order to be sustainable.

Since the welfare of future generations is unknown and unknowable, this approach demands the preservation of the environmental prerequisites that preserve the potential for efficient intergenerational welfare. The preservation of the environmental infrastructure so as to ensure efficient intergenerational welfare is proposed.

The BCL approach endorses those evolutionary paths that ensure the biological and environmental conditions for a biologically-healthy human race as well as for the unconditional shaping of preferences and their satisfaction in generations to come. In this context, intergenerational development paths that deplete the environmental infrastructure and the conditions for welfare attainment are deemed inferior, because they do not result in the efficiency of the potential welfare.

In essence, our proposed framework aims to ensure the ‘environmental rights’ of future generations, which are considered to be as important as those of the present generation. These environmental rights allow future generations to satisfy their biological needs without having to compromise their biological status. Furthermore, the same environmental rights provide all generations to come with the environmental infrastructure that will allow them, based on the natural environment, to shape their preferences without constraints other than those imposed by the natural environment. The environmental rights of future generations cannot be compensated. This perception leads to the preservation of the potential for efficient evolution in intergenerational welfare. The only caveat concerns the allocation of non-renewable resources because, in terms of efficiency, we have no way of comparing alternative intergenerational allocations.

Evidently, our approach does not require the preservation of all existing environmental infrastructure everywhere and for all time as a condition for sustainability. In other words, the BCL approach does not require "*a world exactly as the Iroquois left it*" (Solow, 1993). Rather it calls for the preservation of the capacity of the environment to ensure the biological-healthy status of humankind and the unconstrained shaping of preferences by future generations. In this context, the imaginary application of BCL criteria in the past would not have meant that we inherited a world "*as the Iroquois left it*". But we would have inherited a world without the current severe environmental problems that are undermining the biological health of the human race (indicative examples are water pollution, climate change and atmospheric pollution), and without the foregone potential for shaping preferences (lost biodiversity, and so on).

Furthermore, the BCL approach (the preservation of ecological health and ecological integrity) sets the necessary limits within which environmental policy avoids paths that restrict future generations’ opportunities. In fact BCLs define those limits within which democratic societies can define the targets of short-run environmental policies (Bromley, 2004). They transmit from science to democratic society the necessary ‘information’ and ‘knowledge’ for making informed policies. The management of BCLs should be governed by the ‘inalienability rules’ proposed by Bromley (1989), prescribing that BCLs cannot be substituted with any form of compensation.

An important aspect of the proposed approach is that there is no need for substantial revision of mainstream economics thinking before investigating ESED within an appropriate bioeconomic context. Economists trained to work with mainstream and traditional methods are therefore able to absorb the requirement for sustainable development into their own cognitive framework. At the same time, the essential priorities of a bioeconomic approach are served.

Is the proposed approach a bioeconomic one? Clearly, fundamental concepts and criteria from biology and ecology penetrate economic thought and are incorporated functionally within it. Biological integrity, biological-ecological health, ecosystems functions and processes enter the evaluation of Pareto-efficiency. Is the proposed approach policy-relevant, and is it operational? BCLs and the regeneration rate of renewable resources are observable and measurable entities. They can be included in a decision-making process and lead to informed decisions. Limited knowledge may create uncertainty. However, there is room for effective policy design, and the lack of knowledge is not an insurmountable obstacle.

Essentially, the present proposal sets up a forum for debate among economists, as well as between economists and biologists so that certain crucial issues may be discussed:

- How can the knowledge and findings of biology and ecology be incorporated functionally into the essential, novel bioeconomics?
- Which are the appropriate social and economic entities which should adopt an intergenerational context of welfare?
- Can individuals and companies – the leading actors in today's economic life – serve such a welfare consideration?
- What role will markets play?
- Can the institutions of state and society play a role in the preservation of the 'environmental rights' of future generations?
- Is ESED a purely anthropocentric concept, or is it able to incorporate functionally non-anthropocentric rationales which reflect contemporary trends in conservation biology and ecology?

These questions suggest that there is still a long way to go in dealing with long-range bioeconomic issues.

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