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Sustainability, Human Welfare, and Ecosystem Health

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ABSTRACT: Two types of sustainability definitions are contrasted. 'Social scientific' definitions, such as that of the Brundtland Commission, treat sustainability as a relationship between present and future welfare of persons. These definitions differ from 'ecological' ones which explicitly require protection of ecological processes as a condition on sustainability. 'Scientific contextualism' does not follow mainstream economists in their efforts to express all effects as interchangeable units of individual welfare; it rather strives to express sensitivity to different types and scales of impacts that present activities can exert on the future. We can therefore express the moral obligation to act sustainably as an obligation to protect the natural processes that form the context of human life and culture, emphasizing those large biotic and abiotic systems essential to human life, health, and flourishing culture. Ecosystems, which are understood as dynamic, self-organizing systems humans have evolved within, must remain 'healthy' if humans are to thrive. The ecological approach to sustainability therefore sets the protection of dynamic, creative systems in nature as its primary goal.

KEYWORDS: Sustainability, ecological management. obligations to future, welfare, intergenerational equity, irreversibility.

The goal of 'sustainability' has emerged as a rallying cry for a broad spectrum of advocates of both environmentalism and rational development. The term sustainability was first popularized in the field of resource use, and it initially had a fairly precise application in phrases such as 'maximum sustainable yield', which represents the highest level of exploitation consistent with maintaining a steady flow of resources from a forest or fishery. Today, however, the term is used much more broadly to include, for example, levels of pollution and degradation of natural systems that are consistent with maintaining current levels of use and enjoyment of those systems. In the context 'sustainable development', it must be used in the broader sense, and hence it is in this broader sense that the term has become a shibboleth of mainstream environmentalists.

It is no doubt useful, in policy discussions, to have a term like ‘sustainability’, which, like ‘conservation’ in days of old, can stand as a label for the many activities of environmentalists. The danger is that the term, like ‘conservation’ before it, will become a cliché.¹ Nobody opposes it because nobody knows exactly what it entails. To avoid this trap it will be necessary for environmentalists, with the help of scientists and philosophers, to develop, explain and justify a theory of environmental practice that gives form and specificity to the goal of sustainability. In particular, what is needed is a set of principles, derivable from a plausible core idea of sustainability, but sufficiently specific to provide significant guidance in day-to-day decisions and in policy choices affecting the environment.

As a first step in giving form to the definition, it is useful to note that the term implies sustainable *use*, so it would appear to exclude severely moralistic approaches, such as positions of extreme deep ecologists who argue that the natural world ought not to be considered ‘resources’ for human use at all.² At the other extreme, advocates of unlimited economic growth, who argue that it is wrong to place any constraints on the ability of the free market to generate goods and services in response to consumer demands, would reject the implication that environmental concerns justify any constraints on the use of nature.³ Between these extreme positions, however – and I think it is safe to say that these extreme positions have very few advocates – lie the vast majority of environmentalists,⁴ who believe that use of the environment is morally acceptable, but that this use is constrained by obligations not to misuse the environment in unsustainable ways.

PART I: SUSTAINABILITY AND HUMAN WELFARE

Today, the most often-cited definition of sustainability is that of the Brundtland Commission’s report, *Our Common Future*: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”⁵ The Commission followed this definition with a formulation of the “two key concepts” of their definition: “the concept of ‘needs,’ in particular the essential needs of the world’s poor, to which overriding priority should be given”, and “the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs”.⁶

Since the exact meaning of sustainability will depend upon the specification of the ‘limitations’ mentioned in the second concept, it is notable that the Brundtland definition states these as determined essentially by “the state of technology and social organization”. Sustainability is therefore defined as an intertemporal relationship between *human needs* and *human productive capaci-*

ties, as a relationship between human welfare at different stages of human development. While the environment is mentioned, it appears as a passive element in the equation – needs are human-determined, and limitations are seen as human limitations. The environment does not impose any non-negotiable limits on sustainable use, independent of limitations on the abilities of humans to control it. Any limitation on use of the environment may in principle be overcome by some new breakthrough in technology and social organization. Our obligation, on this view, is to balance present fulfilment of needs against the ability of future generations to fulfil their needs.

The Brundtland definition, then, can stand as characteristic of one broad approach to sustainability, which I will call the ‘social scientific’ approach, both because it is popular among social scientists, such as demographers and economists, and because it focuses most empirical attention on human demands and on characteristics of technical and social innovation.⁷

While the Brundtland definition was intended as a relatively ‘neutral’ definition, attractive to a broad range of environmentalists and developmentalists, we can now see that it may not be. The implication that there can be no insuperable shortages in resources precludes, by the very definition of sustainability, limitations imposed by characteristics of the environment itself: characteristics that might limit its ability to produce consumable goods or absorb human wastes. On the Brundtland approach, projections of economic and social growth can be calculated without accounting for the *scale* of human activities.

Intuitively, this implication that nature sets no natural limits on economic uses is implausible; it implies that no human activity will, in principle, be precluded by shortages of resources. This implication seems to contradict the obvious fact that the stocks of any given resource are finite, and that some of them, such as copper ore, are quite limited.⁸ The denial of natural limits does not challenge this fact directly, however. It recognizes that stocks of non-renewable resources will decline and the price of raw resources will rise; the key to maintaining this position rests on a high degree of confidence in the intersubstitutability of resources. The finitude of copper does not cause a limit on economic growth because, as the price rises, a substitute resource will replace it. Similarly, as the cost of disposing of pollutants and wastes increase, entrepreneurs will be stimulated to develop alternative means of recycling and disposal. I am suggesting, then, that social scientific definitions of sustainability presuppose a very strong principle of intersubstitutability of resources, indeed, a Principle of Infinite Intersubstitutability (PII). This principle is inherent in the definition of sustainability as a simple balance of ‘human welfare’ across time. Environmentalists, I submit, will question PII. They should, therefore, be wary of attempts to define sustainability simply as a matter of human technology and welfare.⁹

It can be argued that the assumption of PII is intimately tied to the unidimensional value analysis of the mainstream economic paradigm. One will

find PII plausible only if one assumes the interchangeability of labour, resources and capital, and that all value can be represented as prices in markets. Interchangeability is essential to the central idea of mainstream economics; that all choices can be understood incrementally, as consumer choices at the margin.¹⁰ If sustainability is to be a simple problem of balancing welfare across generations, then human welfare must be understood incrementally and interchangeably as it is in mainstream economics. Provided we leave our descendants *richer* than we are, according to this analysis, we cannot have done wrong; the future can simply trade its wealth for amenities, substitutes for lost resources, or a pollution-free environment. In an incremental system of value in which all values are interchangeable and all resources have, with requisite capital, adequate substitutes, environmental constraints need be given no special pre-emptive status.

To recognize limits inherent in nature itself would be to introduce discontinuities into the analysis. If over-consumption of passenger pigeons were analysed in 1900, according to the mainstream economic paradigm, profits resulting from over-exploitation could have been deemed 'beneficial' to the future as capital capable of generating new sources of protein. If, however, one insisted that passenger pigeons represented an irreplaceable resource, one would have argued that continued consumption of squab, even as the stocks plummeted toward extinction, represented an unrecompensable harm perpetrated by one generation on subsequent ones.

It is tempting to set out to show that the economic paradigm, despite its unquestioned advantage of simplicity (in that it can represent all values on a single scale of welfare), is too simplistic to deal with questions of intergenerational equity. In particular, it could be argued that the incrementalist model of mainstream economics (which seems to be presupposed in the Brundtland definition) is ill-suited to deal with policy problems in which incremental choices can have irreversible effects that will have impacts over very long periods of time.¹¹ Space will not permit such an argument here. Instead, an alternative conception of intertemporal welfare will be proposed and explained. This conception, 'scientific contextualism', does not flatten out all decisions into interchangeable units of individual welfare, but instead, retains a sensitivity toward different types and scales of impacts that the present can exert on the future.

PART II: A CLASSIFICATION OF RISKS

The flattening-out approach to judging intergenerational impacts, measuring intertemporal welfare according to a single scale of present valuations, usually dollars, ignores apparently important differences in the types of impacts the

present can have on the future. A broad and inclusive conception of sustainability must gauge the ability of the future to deal with pollution and waste as well as with declining stocks of resources.¹² For the sake of a convenient terminology, and because it seems reasonable to treat some present activities as creating a 'risk' of future shortages of resources and sinks for waste products, let us propose an intuitive scale for classifying types of risks that the present may impose on the future, as in Figure 1.

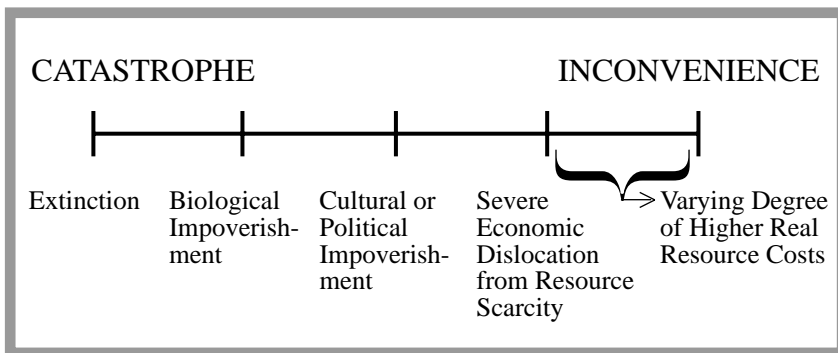


FIGURE 1.
Typology of Risk Severities

This scale recognizes the apparent difference between activities such as burning fossil fuel in great quantities, which may include considerable risk that the planet will become uninhabitable by future humans at one extreme; and less cataclysmic results, such as filling all available waste dumps, which might force future generations to give up disposable diapers and return to the old-fashioned practice of washing diapers. Because one of the apparent weaknesses of the incrementalist model is that it does not deal well with irreversibilities such as species extinctions, we can remedy this weakness by introducing a scale of comparative reversibility of present decisions. If some decisions we make today are easily reversible, then capital or know-how may be a reasonable substitute for some forms of environmental protection. Conversely, major cataclysms would be irreversible. Therefore, we can plot our intuitive scale of types of future risks against a scale of reversibility, creating a decision grid as represented in Figure 2.

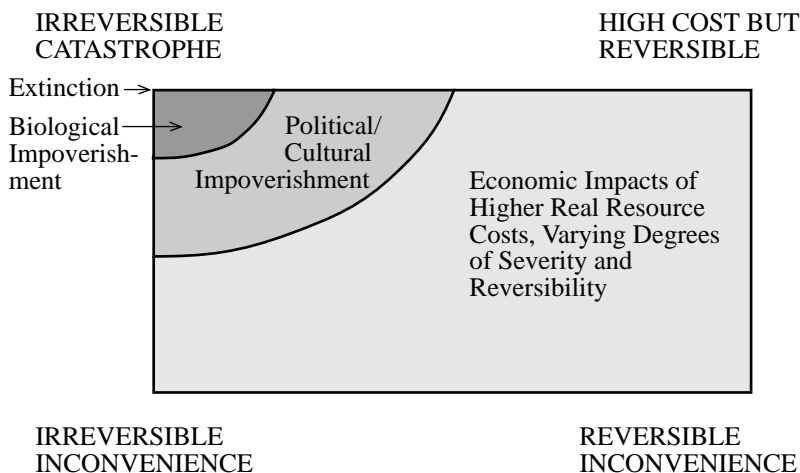


FIGURE 2.
Risk Typology: Severity and Reversibility

The decision space here defined will include, in the far east, the southeast, and the far south portion of the space, decisions that we will consider simple trade-offs. If the negative impacts of our activities on the future result only in easily reversible changes, or if the impacts result only in minor inconveniences, we can figure that we have been 'fair' to the future provided we make available capital and techniques sufficient to reverse or counterbalance those effects. Decisions that have possibly cataclysmic impacts or irreversible consequences, on the other hand, will not be open to trade-offs. Decisions that fall in the northwest portion of the decision space will be governed by non-negotiable constraints. A slightly less constraining decision rule, the Safe Minimum Standard of Conservation (SMS), might be applied in this 'red' area. This rule advises: Protect the resource (natural process, species, etc.) provided the costs are bearable.¹³

I am hypothesizing, then, that our obligations will be least negotiable in the NW corner of the decision space and that these obligations will decline along all vectors away from that corner. Figure 2 also represents the above-mentioned insight that the degree to which one believes in intersubstitutability of resources will determine the relative size of the decision space governed by non-negotiable constraints. In the limiting case of a belief in PII, the decision space governed by non-negotiable constraints will be null – all risks are recompensable with adequate capital and technological development. As one's faith in intersubstitutability decreases, the northwestern space will expand, representing more and more decisions as governed by non-negotiable constraints.

We can refer to approaches to sustainability that recognize some decisions with future impacts as governed by non-negotiable constraints and some decisions governed by trade-offs as ‘hybrid theories’ or as ‘two-tier systems’.¹⁴ They recognize at least two measures of value that cannot be aggregated together – one set of obligations may trump another. Two-tier approaches therefore differ from the single-tier systems of micro-economics and of other utilitarian approaches, which see only interchangeable units of welfare as the measure of sustainability, by recognizing some constraints that cannot be traded off. The two-tiered approach eschews simple aggregation in favour of lexically ordered rules.

The moral status of these non-negotiable obligations in the NW corner is, of course, open to much debate. Some of my colleagues in environmental ethics would insist that these obligations be formulated as protecting values ‘intrinsic’ or ‘inherent’ in nature, positing values independent of humans.¹⁵ Others would posit basic rights of future persons, which would trump mere consumptive interests of present persons.¹⁶ Another understanding of non-negotiable obligations, the one to be explained here, is morally anthropocentric, but based in a holistic conception of the natural systems on which humans depend. If it turns out that nonhuman rights or rights of the not-yet-existent can be specified later, they could be added on, further strengthening the already strong obligations involved in contextualism. The point I wish to stress here is that the logic of two-tiered, hybrid systems is similar, and this sets them apart from the single scale of values approach of many social scientists.

PART III: SCIENTIFIC CONTEXTUALISM

Consider an approach to sustainability that recognizes obligations of the present generation to future generations, but views these obligations holistically – as not reducible to individual satisfactions or preferences.¹⁷ These obligations are of the type that would be suggested by Edmund Burke’s understanding of a society as “a partnership not only between those who are living, but between those who are living, those who are dead and those who are to be born”,¹⁸ and these obligations would be based on a belief that the continuance of the human species is a good thing.

Having posited such a value and cross-generational obligations not defeasible into individual satisfactions, let me now argue that, if we have such obligations – and I think we do – we can now posit an alternative approach to understanding sustainability. This approach recognizes that there are non-negotiable obligations regarding our use of resources (the NW corner of the decision space is not empty), and that those obligations can be understood as the obligations the present has to perpetuate the conditions necessary for the continuation of the human species and of its culture. The exact nature of these

obligations must be determined scientifically, as we understand the impacts human activities have on their larger context. If, following Aldo Leopold's land ethic, we insist that this larger context can only be understood as a complex ecological system, sustainable activities are activities that do not destabilize the large-scale, dynamic, biotic and abiotic systems on which future generations will depend. Scientific contextualism applies a variety of moral rules, placing priority on different values in different situations. If plausible scientific models indicate that a realistic, if not necessarily probable, chain of processes could result in cataclysmic effects, we are in the 'red zone', and the SMS standard applies.

Admittedly, the information necessary to act sustainably in this sense would be very hard to obtain. But our concern here is mainly conceptual. Assume, for example, that models showing rapid and accelerating warming of the atmosphere in response to a build-up of greenhouse gases were strongly verified, and that these models showed increases, 50-100 years in the future, too rapid for civilization to survive. I believe that most people would say, once most scientific uncertainty was removed, that such a scenario would trigger non-negotiable constraints limiting current behaviour. Examples such as this are important, because they help to shift the burden of proof from those who would institute constraints on economic growth to those who would flirt with cataclysmic changes in the context of human adaptation. If there are clear examples in which non-negotiable constraints would exist, growth enthusiasts must show that their proposed activities violate no such constraints.

We know that undisturbed natural systems are able to maintain themselves across time, that they will keep their energy pathways open, and that they will maintain their productivity. Once a system is disturbed, effects cascade through the system; if those effects are of the sort that the system is used to, and can assimilate, it does so. If, on the other hand, the disturbance is so pervasive or so new that the system has no means by which to damp out its effects, the system crosses a threshold; and humans, as well as members of other species, who are adapted to systems with a given set of characteristics, may be unable to adapt to accelerating and cascading changes in their habitat. For example, humans with light skin pigmentation, a trait which evolved in a time of relatively small exposures to ultraviolet light in temperate climates, may be unable to adapt to an earth with less upper-atmosphere ozone.

In a contextual analysis, individual behaviours are not the main focus of environmental ethics – it is trends in those behaviours that determine whether they will have intergenerational impacts. For example, if one farmer cuts and clears his woodlot to plant wheat, this is not wrong, as long as his land is not on a highly erodible slope and provided his action is not copied by all of his neighbours. The moral status of this activity depends not only on the content, but also on the context, of the action. If Farmer Jones plants wheat and Farmer Smith lets his wheat field go fallow, no trend is instituted, and there is little likelihood

that the action will trigger non-negotiable constraints. If most farmers follow Jones, conditions ripe for a dust bowl or desertification may be created. Scale is crucial in determining when a red-zone decision is faced.

Expressed metaphorically, contextualism is organicism – the biota is a living system which has an internal, self-perpetuating organization – but organicism minus teleology. Contextualism need not posit a metaphysical value in the supraorganism, just as it need not posit independent value of wholes.¹⁹ But contextualism does recognize the importance of protecting the processes sustaining self-organizing systems through time. For example, once Leopold fully understood the implications of a systems-oriented approach, he fell back upon the recommendation that we practice something akin to preventive medicine.²⁰

Leopold's theory of sustainable management envisioned hierarchically organized systems, with human activities impacting them, not individually, but in larger trends.²¹ Technology and population growth have given human cultures the ability to alter larger and normally slowly-changing systems of ecology, climate and atmosphere, and to initiate oscillations and fluctuations in these systems. Since we have evolved to live within systems that change slowly, such activities play Russian Roulette with the options of the future. Our generation could cause irreversible changes much too rapid for future generations to adapt to, either physiologically or culturally.

Scientific contextualism places a heavy burden on scientific models to help us determine which activities may have long-delayed, but potentially catastrophic, consequences. The contextualist paradigm of environmental management interprets the larger systems under impact from human activities in mainly ecological terms. An essential element of the contextualist approach to management will be a commitment (non-negotiable constraints) to protect the health and integrity of ecological systems. The contextualist paradigm is not, however, *simply* an ecological paradigm – as human impacts grow, biotic systems, and also atmospheric and climatological systems, are inexorably affected by the aggregated impacts of human economic and other activities.

While I agree with Leopold that these larger impacts should be understood through ecology, because humans are, after all, evolved animals who relate as living things both to the biota and to larger, abiotic systems, contextualism also recognizes the role of non-biological sciences in defining the limits of our impacts on our larger context. For that reason, I call the approach to sustainability sketched here 'scientific' contextualism.

PART IV: HEALTH, INTEGRITY, AND SUSTAINABILITY

The idea that there is an obligation to protect the health and integrity of ecological systems rests firmly upon the premise that natural systems are self-organizing in an important sense. This is a difficult concept, and it must be carefully explained

and qualified – a task that can only be begun here.²² Recognizing that natural systems change constantly, intertemporal stability is conceived as a scalar relation between human activities and their larger environmental context. Contextualism assumes that the self-organization of large systems is essential to future generations and that the ability of those large, self-organizing systems to assimilate human impacts is large, but not infinite. These systems provide the context within which we have evolved. Because they change more slowly than culture, these large systems set the ‘stage’ for human activities. They therefore give meaning to human culture. At the same time, the system is unquestionably dynamic. Stability only exists relative to differing scales of time; we might say that stability is a well-founded illusion.

Autonomous systems overcome entropy; autonomy is the characteristic of systems that allows self-organization. Given this operational definition of autonomy, we can define sustainability as follows. Sustainability is a relationship between dynamic human economic systems and larger, dynamic, but normally slower-changing ecological systems, such that: (a) human life can continue indefinitely; (b) human individuals can flourish; (c) human cultures can develop; but in which (d) effects of human activities remain within bounds so as not to destroy the health/integrity of the environmental context of human activities.

But how are we to define ‘health’ and ‘integrity’? I doubt that one can understand a definition of sustainability without understanding the system of concepts and principles that surround it. Sustainability, when understood within the atomistic, incrementalist paradigm of welfare economics, reduces to a question of balancing interchangeable units of welfare across time. If, as we are hypothesizing here, there are non-negotiable constraints that mandate protection of large autonomous systems of nature, those constraints must be expressed in a richer and more complex paradigm.²³

So the goal of specifying practical guidelines will require a ‘paradigm’ of ecological/contextual management, a set of concepts and principles that can guide attempts to protect and restore ecological systems. Let me begin by citing and agreeing with the definition of Faber, Manstetten, and Proops, who note that ‘ecology’ combines, etymologically, the Greek ideas of ‘house’ with their idea of ‘logos’, which they translate as concept/structure, and define ecology as “the science of the principles of the self-organization of nature”.²⁴ Thus defined, it is part of the specification of the field of ecological management that its subject matter is self-organizing. This definition also ensures that ecology, not economics, will be the new ‘fusion point’ of the sciences, because economic activities are understood as one type of ecological activity, one that takes place within the economic system of one (however dominant) species.²⁵

Our current task is to build upon this approach to management by providing more elements of the ecological paradigm of environmental management. To that end, I suggest five Axioms of ecological management:

- (1) The Axiom of Dynamism: Nature is more profoundly a set of processes than a collection of objects; all is in flux.
- (2) The Axiom of Relatedness: All processes are related to all other processes.
- (3) The Axiom of Hierarchy: Processes are not related equally, but unfold in systems within systems, which differ mainly regarding the temporal and spatial scale on which they are organized.
- (4) The Axiom of Creativity: The autonomous processes of nature are creative and represent the basis for all biologically based productivity. The vehicle of that creativity is energy flowing through systems which in turn find stable contexts in larger systems, which provide sufficient stability to allow self-organization within them, through repetition and duplication.
- (5) The Axiom of Differential Fragility: Ecological systems, which form the context of all human activities, vary in the extent to which they can absorb and assimilate human-caused disruptions in their autonomous processes.

These Axioms function, in practice, in conjunction with a normative definition of ecosystem health/integrity. I begin by proposing a definition of integrity. An ecological system has maintained its integrity if it retains:

- (a) the total diversity of the system, the sum total of the species and associations that have held sway, historically;²⁶ and
- (b) the autonomous processes (systematic organization) that maintain that diversity, including, especially, the multiple layers of complexity through time.²⁷

It is useful to have two, related concepts to describe ecosystem wellbeing, as Leopold noted in his comparison of succession after the plough in Kentucky and in the American Southwest.²⁸ In both cases, the integrity of the system was compromised – including loss of total diversity and invasion by exotics. The difference, Leopold noted, was that bluegrass represented a new stable point, capable of maintaining itself across time. This system lacked the integrity of systems like Rio Gavilan, that maintained their ‘aboriginal health’ (including their historical mix of species), but maintained a ‘healthy’ equilibrium nonetheless.

I am suggesting that we use the term ‘integrity’ as the stronger term – though it certainly can admit of degrees – while we use ‘health’ to designate the somewhat weaker concept that describes the Kentucky bluegrass system. Integrity, in other words, emphasizes both clause (a) and (b). System S1 maintains greater integrity than system S2 if S1 retains not only enough complexity to maintain autonomous functioning, but also maintains more of its original species, populations, micro-habitats, and processes of interaction. A system is healthy if it maintains its complexity and autonomy/self-organization.

Within this dynamic, contextualist paradigm we can understand the centrality of the goal of protecting biological complexity. Complexity is directly related to self-organization, and self-organization is an essential part of ecosystem health and integrity. And thus we understand the non-negotiable obligation to protect biodiversity: it is an obligation to future generations to protect the diversity and, even more important, the complexity of self-organizing systems. This obligation requires protection of complex processes of ecosystems.

CONCLUSION

I have sketched two broad approaches to understanding sustainability, recognizing that this keystone concept of modern environmentalism can only be given meaning as a part of a constellation of concepts and methods – a paradigm, as some would say. The social scientific approach, which sees sustainability as a relationship between levels of welfare in the present and the future, defines sustainability within an incrementalist paradigm that interprets all values in a common measure, such as dollars or present satisfactions. The advantage of this paradigm, and its proposed approach to sustainability, is that this approach expresses the sustainability relation in interchangeable units; judgements regarding intergenerational fairness can therefore be understood as a balance between commensurable values across time. This incrementalist approach, however, has the attendant disadvantage that it does not deal very well with discontinuities and irreversibilities – and those who worry about global environmental problems such as the greenhouse effect and loss of species diversity emphasize concerns of precisely those kinds.

I have therefore sketched an alternative framework for understanding sustainability, based on a two-tiered system of values, some of which are interchangeable and able to be traded off, and some of which are non-negotiable. Scientific contextualism relies on information and models from the natural sciences to determine which decisions carry significant risk of cataclysmic and irreversible results; and, hence, when non-negotiable moral constraints trump interchangeable measures of individual welfare. This approach *balances* short-term economic and long-term ecological concerns, but does not *reduce* them to a common metric. Environmental policy is constrained by *both* ecological and economic limits; economic concerns predominate when risks are not catastrophic or irreversible and when the areas affected are relatively small. Non-negotiable, intergenerational obligations predominate when decisions carry risk of irreversible or catastrophic change in those large-scale systems on which the human species depends.

NOTES

¹ See Caldwell, 1990, p. 177.

² It seems to me questionable that anyone consistently holds this position in its most extreme form, even though certain passages in the writings of deep ecologists seem to consider all use of nature a violation of its intrinsic value. For a fuller discussion of the policy implications of deep ecology, see Norton, 1991, chapter 12.

³ See, for example, Kahn, 1982.

⁴ Data from the late 1970s showed only eight per cent of environmentalists advocating all of the tenets of deep ecology (Mitchell, 1980). I am unaware of more recent data on this subject. As for the other end of the spectrum, I have argued in *Toward Unity Among Environmentalists* that advocacy of some market constraints to protect environmental values provides a minimal defining characteristic of all environmentalists.

⁵ World Commission on Environment and Development, 1987, p. 43.

⁶ Ibid.

⁷ See Ehrlich and Ehrlich, 1986, pp.8-10.

⁸ See Woodwell, 1985, for a useful, recent discussion of this difficult issue.

⁹ See Daly and Cobb, 1989, pp. 72-6, for a more positive characterization of the Brundtland definition. Daly and Cobb describe the Brundtland definition as “vague”, but artfully so, and believe that it will give rise to more specifically biological criteria.

¹⁰ For a careful and detailed explanation of how the mainstream economic paradigm reduces environmental values to increments of willingness-to-pay, and how this paradigm consequently ignores problems of scale and magnitude of throughput, see Daly and Cobb, 1989.

¹¹ This argument is made, for example, by Kneese and Schulze (1985), who can be considered, in general, proponents of the mainstream micro-economic paradigm.

¹² Indeed, many environmental and resource analysts now believe that problems of waste disposal will prove far more intractable than will problems of resource availability. See Faber, Manstetten and Proops, 1990.

¹³ Ciriacy-Wantrup, 1952.

¹⁴ For a classic economic treatment, see Page, 1977. Also see Page, 1991, and Toman and Crosson, 1991.

¹⁵ See, for example, Callicott, 1989, and Rolston, 1988.

¹⁶ I have argued elsewhere that both of these approaches suffer serious conceptual difficulties and will not repeat those arguments here. See Norton, 1982a and 1982b.

¹⁷ See Norton, 1989, for an explanation of a decision model that relies on general obligations to the future – obligations that are owed to no specifiable individuals.

¹⁸ Burke, *Reflections on the Revolution in France*, pp. 93-4.

¹⁹ See Ulanowicz, 1986, p. 25, for a concise explanation of how self-organization can be treated independently of teleology.

²⁰ See Leopold, 1939, and Hargrove, 1989.

²¹ See Norton, 1990.

²² See Prigogine and Stengers, 1984; Gleick, 1987, and Ulanowicz, 1986, for a comprehensive examination of this and related concepts.

²³ See Carpenter, 1990.

²⁴ See Faber, Manstetten, and Proops, 1990.

²⁵ See Leopold, 1939.

²⁶Total diversity (Gamma diversity) is defined as a function of within-habitat diversity (Alpha diversity) and cross-habitat diversity (Beta diversity). It is the diversity characteristic of a landscape composed of many habitats and micro-habitats. See Norton, 1987, pp. 32-3.

²⁷These axioms were introduced in Norton, 1991.

²⁸Leopold, 1949, p. 206.

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