October 1994
RWU - 4803

*Social and Economic Dimensions of Ecosystem Management*
Forest Service, USDA
North Central Forest Experiment Station
1992 Folwell Avenue
St. Paul, Minnesota 55108
(612) 649-5164

# Forests as Natural Capital: Parallels, Problems and Implications

**Dennis P. Bradley** and **Zhi Xu**

## Table of Contents

# Forests as Natural Capital:

## Parallels, Problems and Implications

Dennis P. Bradley and Zhi Xu

*Forest Economist*, North Central Forest Experiment Station, Forest Service, USDA, St. Paul, MN 55108 and *Research Associate*, College of Natural Resources, University of Minnesota, St. Paul, MN 55108

The authors offer their deepest thanks to Bernard J. Lewis, former Research Associate at the College of Natural Resources, University of Minnesota, for his extremely helpful comments on both organization and content, especially regarding the social aspects of resource use and management.

Introduction

Forests are simultaneously part of the biosphere, ecosystems on their own account, the source of materials essential to human survival, and not least, the origin of deep human symbols and meanings. While these insights may not be new, as the scale of our impacts on ecosystems has grown to global proportions, integrating the multi-faceted character of forests into our management actions--always a difficult task--has become even more so. Further, new knowledge about the complexities of ecosystem and social system interactions suggest even greater need to change how we view these systems and as a result, how we use them to survive. In other words, a fundamental incoherence between our thoughts and actions *vis-a-vis* Nature and Society may be at the root of many difficulties.

This incoherence is evident in our difficulty defining what we mean by sustainability or ecosystem health, and in recent debates whether modern economies and mass consumption threaten the long-term productivity of forests and other ecosystems. A key to this difficulty is that such meanings are inescapably confounded by positivist and normative mixtures of facts and values. That is, while our efforts to survive must be guided by the best science that we can muster--and at its best, science certainly strives for value-neutrality--notions of health and sustainability unavoidably involve not only objective facts but human purposes and aspirations. Even as scientists and resource professionals who should be aware of such difficulties, we understandably have trouble separating these domains. Moreover, such purposes and aspirations complicate enormously our collective and individual actions because of the very problems of defining, at the outset, the nature of our objective--sustainable societies and ecosystems--for which evolutionary change is a fundamental characteristic. Such evolution arises not only from inherent dynamics of these processes themselves but now more than ever before, from their interactions. New evidence emerging from both the natural and social sciences suggests the need to more realistically confront ecosystem limits.

To this end, we examine the emerging idea that forests and other ecosystems may be viewed as both natural analogs of, and complements to, economic--that is, man-made--capital. But we also suggest that--due to the unique properties of all physical systems, living or not--this analogy cannot be transferred wholesale. At the same time, because a discussion of capital cannot be confined to economics or ecology, we consider broader social processes when the reproduction of various social structures and processes in addition to those underpinning economic action is implicated.

Beginning with a brief discussion of capital as an integrating concept, we: (1) consider the nature of forest ecosystems with complex features that have been inadequately recognized in the past; (2) highlight some problems in the treatment of ecosystems by neoclassical and environmental economics, (3) review key economic concepts of capital that raise special difficulties when applied to ecosystems, (4) describe several other problems with treating ecosystems as capital that arise from their thermodynamic and emergent characteristics, (5) consider the bases of capital valuation, both those rooted in economics and in broader features of social relations; (6) highlight problems with ecosystem depreciation and its re-capitalization; and finally (7) outline the implications of the above for an accounting framework that may yield a more realistic picture of ecosystem integrity for economic and social purposes.

## Capital as an Integrating Concept

The fundamental importance of *capital* is aptly characterized by Bliss (1975): "When economists reach agreement on the theory of capital they will shortly reach agreement on everything else." He suggests that the roots of many, if not all, disagreements in economic theory lie in varying conceptions of capital and its closely related notions of wealth and income. We hope to clear up some of these difficulties. In contrast to a newer view that Capital deals with the *private ownership of the means of production*, our discussion focuses on an older, less ideological view that embodies two apparently contrasting ideas: The first idea encompasses the dialectical objects of *Wealth* and *Capital*: These objects are dialectical because each requires the other for its existence and because there is a continuous shading of meaning as we move from one idea to its opposite. The second idea concerns the thermodynamic nature of wealth and capital.

First, wealth refers to material goods and services humans must use to survive and includes both those that come either directly from Nature, or from conscious human processes that combine their own labor, raw materials and energy, and Capital in the older sense as Technology. Of course, such technology encompasses human material knowledge, organizational skills, and various machines. But capital also encompasses a society's cultural resources, for these play a central role in the creation of this knowledge and skill, as well as motivating and coordinating social action. In the dialectical way suggested above, some wealth requires human capital for its existence, yet without wealth, capital could not be produced. That is, wealth owes its origins to the ability of a society to find in Nature or to wrest from her by their own efforts, more than needed for immediate consumption. Some portion of the surplus must then be invested in capital *assets* to maintain current, or improve future, income possibilities and so on in a continuous evolutionary process. We generally speak of the output of these complementary capital and wealth producing processes--natural and human-made--as *income*.

The second idea recognizes that, due to their inexorable thermodynamic nature, wealth and capital necessarily deteriorate even when continuously maintained at some "cost," which at minimum requires a reduction in current consumption. That is, the gross output of our productive efforts or of nature itself cannot be considered income to be consumed now: some must be saved to maintain this capacity or even better, invested in new and more powerful knowledge and processes--to be utilized in maintaining or even improving our quality of life. This recognition is the basis of complex institutions to achieve this end--indeed, these institutions are the basis for describing our society as *Capitalistic*.

As mentioned earlier, the term *Capital* is usually distinguished from the other major factors of production mentioned above--Labor and Land--based on factor *ownership*. But the definition of Capital in this paper encompasses *all* the agents of the productive process, and is more in line with the notion envisioned by Adam Smith (Schumpeter 1954). Smith recognized both machine and wage capital and saw the necessity to distribute any income so that both kinds of capital were maintained into the future. Just as machines (and the possibilities for their development and application) had to be maintained from gross income, so must wage laborers be "maintained" for the same material reasons. That is, such economic reasons were not akin to moral or ethical requirements--although such ramifications exist--but derive from the necessity to reproduce all the material *agents* of the productive process.

But one factor was still left out. The earlier views of Smith and Ricardo (as summarized by Schumpeter), and many economists since then, took the reproducibility of the third agent--Land--largely for granted. Land encompassed all those gifts that Nature provided *gratis* and its indestructibility was largely assumed. Yet, we know better. As a result, can we not postulate that maintaining potentials to develop new ways of doing things, necessarily apply not only to machine capital, but also to ecosystems, to humans, and even to the cultural, linguistic, and institutional fabric that form the backbone of every society? Although many difficulties arise when extending capital theory to all three domains, such a recognition may lead to an integrated understanding of ecosystems, their multifaceted and inseparable linkages with every society and its economy, and ultimately their role in the wider realization of individual and collective ideals.

Such broader concerns, however, exceed the scope of this paper. Our primary focus concerns the idea and its value of viewing *forests* as natural capital. In so doing, we briefly consider forests from three aspects; all of which bear on their significance as capital. From the vantage of ***Ecology***, *forests* are terrestrial *ecosystems* with trees as their most obvious component, but that also include many other plants, animals, microbes, and a complex abiotic foundation. Fueled by solar energy, such systems of species, structures, and processes persist and evolve over time by transforming and recycling various biotic and abiotic components under a wide variety of environmental conditions. Of course, forests are only one of a great many kinds of ecosystems--one level of biophysical structure--within a complex and evolutionary hierarchy of interrelated organizations.

From the perspective of ***Economics***, *forests* are one kind of *resource* that is central to human survival. Using a special language of markets and exchange, economics envisions a world of human individuals motivated largely by self-interest, exchanging resources they own or control for those owned by others. Further, all individuals either consume such resources immediately, save them for future consumption, or "invest" them in the broadest sense to enhance future consumption possibilities.

From the vantage of ***Psychology*** and ***Sociology,*** *forests* and other ecosystems serve many functions in our individual and collective activities, among the most important, as we have seen, is the economic. However, this economic importance by no means exhausts the meanings of forests. Forests as natural settings for human relations and as immaterial reservoirs of symbolic and aesthetic significance to individual and collective identities are *no less important* in determining the future trajectory of human societies than the material processes on which ecology and economics focus. Thus, while the individualistic emphasis underpinning, even dominating, current economic thought may be an understandable starting point, it is now apparent that human possibilities are constrained by ecosystem features and properties in ways not widely articulated. Further complications arise when we recognize that both ecosystem possibilities and limitations, derived in part from the laws of thermodynamics and physics, are themselves evolving and cannot be described exhaustively beforehand. Equally important, forests and other aspects of the natural world, are not significant to humans solely by virtue of their contributions to our material reproduction: Nature serves as a central source of analogy and metaphor which provide essential meanings of what it is to be human. Such meanings involving moral, ethical, and aesthetic dimensions--and also evolving as we learn more about Nature and ourselves--serve essential functions in our social and individual reproduction and therefore, cannot be dismissed as mere amenities with no material significance.

## Forests as Ecosystems

Ecosystems are complex entities comprised of a wide variety of structures, processes, and functions. Such complexity cannot, however, be understood as simply the aggregate consequence of adding together individual ecosystem elements. Rather, ecosystem functions operating through various structures and processes, and even species themselves are emergent properties of the system, with features resulting from the dialectical interplay of parts and whole. In this light, attributes of the *relationships* among elements at any level of system hierarchy may be of a profoundly different character than attributes of the *elements* themselves. Emergent properties, therefore, are not merely the unfolding of features that were already immanent yet somehow hidden, but result from an ongoing creative process and may be entirely novel. Indeed, evolution--of species, of other biotic, abiotic, or even social features at various system levels--can be considered synonymous with emergence. Thus, it can be asserted that an evolving ecosystem's new features (and most important, its consequences for humans), can not be foreseen beforehand by any scientific model, no matter how sophisticated. As Poincare noted, the real world is its own fastest simulator (Soddy 1933).

An important consequence of the above is that an ecosystem which has been 'disordered' beyond its current *capacity* to compensate for, or tolerate change without 'disaster' The terms *disorder* and *disaster* deserve comment. It is often forgotten that these terms are human judgments of inherently value-neutral physical and ecological conditions. That is, one might say that Nature knows nothing of disorder or disaster: such terms are only relevant in light of human purposes and concerns. Thus, this whole discussion is motivated by the desire to more realistically accommodate a growing body of knowledge of how ecosystems and social systems interact and evolve.

--a capacity which is itself an emergent property--will be irreversibly altered so that in a real sense, a new system emerges with at least some entirely new properties. And while many features of the previous system may still be evident, some of them must disappear or be so altered with unpredictable effects on system outputs used by existing species or other subsystems. What is more, such changes may be irreversible, if not thermodynamically then effectively.

It is an ecosystem's stability as a whole--another emergent property--that is suggested by the vague term *ecosystem integrity* and for human purposes, that is of greatest concern in this paper. The products and services which result from an altered and newly emergent system might be less than necessary to sustain various existing species, especially humans, under the new conditions. Moreover, such hazards are themselves an emergent feature of the new system that by its very nature is not amenable beforehand to any "risk analysis." In short, the continued and relatively stable functioning of a forest ecosystem for human purposes very likely depends on maintaining this integrity within some "bounds." And these bounds probably entail maintaining at least the preponderance of the elements of its diversity, structures and processes, even if, given our present ignorance, we do not entirely understand how all these elements interact to yield the integrity See Norton (1992) for more details on interpretation of ecosystem integrity.

we seek. At the same time, human activities are now recognized as perhaps the major source of ecosystem changes--and the scale of these changes will increase the difficulty of maintaining this integrity even in the very short-term (Gleick 1988). All of this has obvious implications for human possibilities, including the role of ecosystem capital for human economic activities.

## Forest Ecosystems as Economic Resources

### Neoclassical Economic Themes and Shortcomings

Our perceptions of ecosystems, including especially how we value them, both contribute to, and are affected by, society's larger value system (Redclift 1993). And due in particular to the current emphasis on--even the reduction to--a largely economic way of valuing all things, ecosystems are often seen in too narrow a light. For example, when a forest ecosystem is brought into the scope of neoclassical economics, its features are categorized and itemized--in the process reduced--so as to facilitate the assignment of economic values. While this works well for many forest outputs such as timber and minerals, the difficulties of capturing the values of many less-tangible, yet equally real characteristics of forests are well known (Bradley and Lewis 1992). Thus, from its perspective of the market with its emphasis on value-in-exchange, forests in their totality as ecosystems, are largely invisible. While the itemization of some forest ecosystem elements has undoubtedly helped us use them more efficiently, it has too often occurred at the expense of ecosystem integrity thereby entailing significant risks.

In addition, because neoclassical economics rests largely on the notion of autonomous individuals--surely a worthy premise, but a very significant and unrealistic abstraction--an *atomization* of human interests parallels its *itemization of forest ecosystem outputs*. While this no doubt also helps achieve *efficient* resource use for at least some purposes (Bromley 1991), it depends for its justification on an ideology that *individual* ownership of economic resources is itself, alone, *sufficient* both to ensure society's survival and to achieve humanity's highest aspirations. Nevertheless, such a position is untenable for it precludes recognizing other key factors influencing the stability and integrity of social systems, except as those requirements could be represented as simple aggregates of individual economic utilities. As a result, economists increasingly considered other so-called institutional factors that regard economic activity as only one aspect of a more complex social whole.

Yet despite many important institutionalist efforts, a simpler vision of economic activity often prevails in practical affairs as well as in policy decisions. Taken together, such an aggregation of atomized interests paralleled by a limited itemization of forest ecosystem components frequently results in decisions that encompass a mere shadow of an ecosystem's holistic features (i.e., its integrity) and therefore inadequately reflect their full significance to humans. We now realize that many ecosystem goods and services, non-economic values, and future potentials thereby depend on the continued integrity of forests as functioning ecosystems. At the same time, real collective or social interests that are essential to the integrity of society, and thereby the health of real individuals, are also disregarded. We shall return to some of these problems later.

## Environmental Economic Themes and Shortcomings

Developed specifically from a heightened awareness of the central role of environmental quality and intact ecosystem functions for underpinning economic actions, *Environmental Economics* attempts to broaden the accounting for costs and benefits through expanding economic notions of value to include non-market goods (or bads) and services (disservices) both now and in the future (Braden and Kolstad, 1991, Brookshire et al. 1983, Krutilla 1967, Kneese 1984, Randall and Stoll 1983, Walsh et al. 1984, Weisbrod 1964). Through various valuation and assessment techniques (Cummings et al. 1986, Dixon and Hufschmidt 1986, Hufschmidt et al. 1983, Johnson and Johnson 1990, Kopp and Smith 1992, Mitchell and Carson 1989), environmental economics seeks, in a sense, to re-construct the environment socially, principally but not exclusively by way of *monetary* valuations.

Such a strategy, however well-intentioned, still shares the difficulties mentioned earlier: Among them; (1) the limited applicability of economic values for managing ecosystems since we don't fully understand how an ecosystem underpins or contributes to an economy; (2) problems in accounting for an ecosystem's potential to satisfy *other* social values or more to the point, to inspire *other* social actions; (3) value aggregations and comparisons across space and time--especially the difficulties relating an action to its possible consequence across the globe, or estimating an ecosystem's "potential" value to *future* generations, and (4) limits inherent in the *social institutions* such as property rights and contracts that underpin market and non-market values (Anon. 1992, Hausman 1993, Cicchetti and Wilde 1992, Kahneman and Knetsch 1992, Peterson and Peterson 1993, Redclift 1993, Sagoff 1993). Based on this brief summary of the emerging insights about ecosystem dynamics and possibilities, and the limitations of neoclassical and environmental economic approaches, we now focus on the difficulties of a wholesale transfer of apparently analogous notions of capital to ecosystems.

## Forest Ecosystems as Natural Capital: Parallels and Problems

We have briefly described the dialectical relationship between wealth and capital, their connection through income, and hinted at the need to apply these notions beyond their traditional treatment by neoclassical and environmental economics. In examining why this is so, we first consider recent additions to concepts of natural capital and environmental assets (El Serafy 1991, Costanza and Daly 1990, Tietenberg 1988). These authors emphasize a perspective of forests and other ecosystems as natural analogs to stocks of economic capital and stress the limited capacity of ecosystems to generate flows or incomes of economic and environmental outputs for sustainable development. This new economic goal that, while surely needing refinement, is still thermodynamically, logically, and practically superior to the more widespread goal of "unlimited economic growth." These authors' treatment of ecosystems as capital can be seen to reflect Clark's (1976) extension of Hicks' (1946) classic ideas to forest and fishery flow levels, stock effects, and optimal harvest rates, while recognizing the inadequacy of Clark's treatment of such assets as *single* sources of capital services to various economic sectors. But problems with extending capital theory to ecosystems also arise because of: (1) the thermodynamic complexity and irreversibility of many biophysical and social interactions; (2) implicit assumptions that present and future generations will similarly value Nature; and not least (3) the necessity for *values* beyond the strictly economic in order to achieve sustainable resource use. That is, despite past and no doubt future successes of the alliance between science, technology, and economics, justifications for economic actions cannot rest solely on economic values, for that would be ultimately self-defeating as well as tautological. We would now like to follow the above authors' lead and consider these other problems in greater detail.

Capital as a *fund* of *services*

Even Hicks' (1974) definition of capital as a stock of real goods that produces an income of other goods and services, and which on its face seemed adequate, confounds several issues that assume critical importance when applying them--developed originally in regard to man-made processes--to ecosystems. Nicholas Georgescu-Roegen's thoughts in The Entropy Law and the Economic Process (1971) may clarify the matter. He reminds us that capital is a fund which serves--in the sense of facilitates--the production process. Stocks of raw materials and intermediate goods flow to, and are transformed by the use of various capital funds in such a process. That is, he contrasts the *use* of *capital services* (in a real sense, as agents) with the actual transformation or *consumption* of *stocks* so that some physical output results. Combining these distinctions, *Capital* is the fund of tangible and intangible assets that provide services used during a production process which consumes tangible *stocks* of raw materials and intermediate goods in their eventual transformation into final "goods." Stocks are consumed in the sense that these are now physically embodied in the product. Over time and dialectically, from stock to service and back again, such products can be intermediate goods, final goods, or even new or renewed capital services.

Key aspects of embodiment relate to what happens not only to the materials consumed but to the energy. Material transformations may be clearer because of their tangibility but are seldom obvious. Since according to the 1st law of thermodynamics, matter and energy are never destroyed, we can trace (albeit often with difficulty) the material inputs to either their presence in the product or as material wastes. Yet the energy required for the transformation also goes through a parallel process. As a product acquires greater usefulness in its structure or location, part of the energy consumed can be considered as embodied in it, even though we may not be able to de-construct the final product into all its material and energy inputs.

Then too, every process results in a great deal of waste energy. Indeed, thermal efficiency--an expression of the 2nd Law of Thermodynamics--is proportional to the differences in absolute temperature (degrees Kelvin) between the process and its environment. And because for most processes of interest to humans, such temperature differences are small, thermal efficiency is necessarily low, seldom exceeding 30 percent, and usually much less than 10 percent. That is, not only can no process attain 100 percent energy efficiency, most processes of significance to humans produce more wasted material and energy than useful product. Such wastes, well-intentioned claims for recycling to the contrary, are largely unrecoverable. Moreover, and often forgotten or misunderstood, because these temperature differences can be increased in only a few important instances, such low efficiencies are unavoidable, with obvious consequences on the direct utility that any resource base can provide. Finally, and perhaps even more important, such wastes remain in the environment with potentially significant often unwelcome consequences for future possibilities.

To summarize, capital provides useful services that can be distinguished from the useful intermediate and final goods and other raw materials because capital emerges from the productive process with its facilitative or service capacity relatively intact. Stocks of raw materials and intermediate goods, on the other hand, do not. These differences are of special significance when applied to ecosystems. Whereas all funds of services and flows of stocks are unavoidably confounded in the dialectical process of their reproduction, such services and flows can be kept reasonably separate only in conventional economic activities. This is due to the fact that ecosystems are simultaneously capital funds of services as well as the very source of flows from stocks to be consumed by humans and other elements of the ecosystems themselves. Moreover, while we cannot avoid converting and altering the physical resources originating in ecosystems, the actual creation of the system from which these resources emerge, is largely an action of nature and outside our abilities (albeit, certainly not outside our influence). Finally, while our influences cannot be denied, our ability to steer such systems over the long term toward some preconceived goal is highly unlikely. We are certain to be surprised.

## Maintaining a capital fund

The problem of maintaining ecosystems concerns us next. Hicks (1946) pointed out that the income resulting from a production process and consumed per unit of time is at its maximum if, over the long run, capital's income producing potential is *not diminished*. Thus, Hick's concept of income, although perhaps originating from a narrower concept of capital than discussed here, implicitly entails a *principle of sustainability*. Somehow capital must remain "intact." In the case under consideration here, while capital services are not *consumed* in production, they *are "*used-up*"* in the sense that even while idle, let alone in heavy use, the laws of thermodynamics work their inevitable deterioration. And since man-made capital cannot repair itself, some of the gross income must be "diverted" from our consumption to maintain and eventually reproduce the fund. The crux or our argument is that capital includes not only human machines, but individuals themselves, their societies, and ecosystems. But regardless of such imperatives, what can we really do in a physical and thermodynamic sense, when it comes to ecosystems?

In the case of an ecosystem as natural capital, such repair or replacement is not strictly possible to the same extent as for man-made capital. As briefly sketched earlier, ecosystems are not static;

their various structures, processes, and functions supporting diverse patterns of biotic and abiotic elements continue to provide their own impetus for the emergence of new forms of organization at every level of ecosystem hierarchy (Shultz 1967). This emergent characteristic of evolving ecosystems--stimulated by internal system interactions, human action, or their combination--may in many important ways confound our goal to maintain "ecosystem integrity." Such changes, regardless of their origin and despite our best intentions--even our complete inaction--may push ecosystems beyond their ability to compensate or tolerate. Moreover, such disorder--more accurately, the emergence of a new order--will not be reversible in many cases. A real risk, especially at the scale of current ecosystem interventions, is that some process, function, and/or species of *material* significance to humans may disappear (Ciriacy-Wantrup 1963).

Such hazards are the basis for increasing calls to moderate--some say radically reduce--our demands on ecosystems while we still have time to maneuver short of draconian limits on population and/or consumption. The consequences of forest ecosystem degradation or simplification may not be reversed as implied by conventional notions of capital repairs or new investments. Depending on the severity of the changes and the inexorable laws of thermodynamics, what we have torn asunder may too often exceed our ability to restore. For example, deforestation for whatever reason and in any locale can alter the biophysical make-up of the region so as to reduce or destroy at least some of its subsequent functions affecting their potential for humans or other creatures (de Groot 1992). Replacing such forests by plantations or other presumably adaptive responses, in turn, often require very large inputs of energy and other materials. Sometimes transported great distances and under questionable social arrangements, the sustainability of such commitments is also in doubt: Nor is the option of restoring what previously existed as easy as so often claimed. That similar irreversibilities may arise in the social arena will be discussed later.

## The duality of forest incomes

Let us now consider the availability of forest ecosystem assets to economies and societies--whether such assets are particular species, broader ecosystem processes, and so on. Such categories include *natural* goods and services which may be considered as *incomes* in the broadest sense. Figure 1 shows how we might classify these incomes according to their varying impacts on economic activity. Two distinctions are required: first, between incomes accruing to *present* or *future* generations; and second, between *actual* or *potential* incomes. Considering income to the *present*, ***Discovered and used*** refers to the incomes of those goods and services known and either used, consumed, or invested by the present. ***Discovered* but *unused*** refers to the income *potentials* of those goods and services which, while known to be useful, are not widely used now due to (perhaps temporary) technical constraints. Considering income for *future* generations, ***Discovered and usable*** refers to the income from those same goods and services which the present generation uses and which future generations will probably also use, if the capacity of capital to generate these goods and services has been maintained. ***Discoverable and undiscoverable as well as usable and unusable*** refers to all the income potentials that *may* one day be converted into *actual* goods and services as we learn more about forests, those that we may learn about but may never find a concrete use for, and those features that we may never uncover. This fourth category lies beyond a so-called *forest capital frontier*. Below and to the left of this frontier are those things which we *can, could, or will* use and thereby can be considered as *actual capital*, and to the other side are those things which we *may* one day use--*potential capital*.

Elaborating further, various authors who distinguished *man-made* from *natural* capital also suggested that *incomes* might be similarly classified. However, such a distinction would be arbitrary because all income for human purposes is a joint result of natural and human action. Moreover, while natural income refers to the goods and services generated by natural capital, its *actual* contribution to the present economy is unavoidably less than its *potential* because some of these goods and services are unused or even undiscovered and therefore can not have economic value in the

present generation's terms. That is, economic value depends both on our level of economic and technological development, *especially* what we *know* about ecosystems. Some of this natural "income" cannot yet be used, is only a *potential,* and therefore, cannot be counted. Yet, paradoxically, if we do not attempt to recognize, if not actually account for these potentials--even if only in a partial, or indicative fashion--natural capital will be undervalued at best. At worst, its *degradation* or *depletion* will go unrecognized perhaps until too late. Such *under-valuations* and resulting depletion would violate Hicks' implicit *principle of sustainability* mentioned earlier.

Environmental economics has attempted to address this problem by expanding notions of value to better encompass *total* values--for example, market and non market; consumptive and non consumptive; or use and non-use. But even non-use values such as *option, existence,* and *bequest* value (Brookshire et al. 1983, Krutilla 1967, Kneese 1984, Loomis et al. 1984, Randall 1991, Walsh et al. 1984, Weisbrod 1964, Braden and Kolstad 1991) that attempt to assess non-economic values and might be considered as estimating future potentials, are not the *future generation's* assessment. All these are still *actual* values because they only reflect the value framework of the present. In other words, such values are at most, only opportunity costs the *present generation* is willing to pay in order to convey these unknown potentials to the future: *Option value* reflects current willingness-to-pay for the *eventual* use of resource opportunities already discovered but unused; *Existence value* reflects current value of the possibility to preserve *undiscovered* and unused resource opportunities; and finally, *Bequest value* reflects the opportunity cost of current moral choices--the cost of our sacrifice for "doing right by" the future generation. Yet while the totality of losses resulting from such irreversible changes to forest ecosystems may not be exhaustively assessed beforehand using only *our* economic costs, this is not to belittle their importance. These costs may motivate us to maintain such potentials in the most cost-effective manner. Most important, such estimates may be all we can muster to determine the feasibility of fulfilling our *moral* responsibilities where it appears that either the present or the future must suffer: No moral law could force us to risk our own lives for some speculative future, even if imminent.

The unavoidable overcapitalization of nature

The last problem to be discussed here was identified by Georgescu-Roegen (1971) and concerns the common analogy between a factory and nature. He points out that this analogy is not only incorrect, but potentially harmful for it exaggerates our maneuvering room when it comes to manipulating ecosystems to fulfill our needs. A common and proper focus of industrial economists is the sequencing of sub-processes and the scheduling of raw material and intermediate assemblies in a factory so that every capital asset is fully utilized. Indeed, such a process is the very definition of *factory*. And again, such a focus applies not only to machinery and raw material but to *labor*--recall Adam Smith's recognition of their commonality as capital. In this fashion, and given the factory's work day, its technology and the skills of its workers, output is maximized and unit cost is minimized. Other features of a factory: once the system is primed so that adequate stocks of intermediate materials and goods-in-process are maintained at every stage, production of final products can be considered instantaneous; further, once primed, a factory can be stopped at any time and restarted with but small losses.

But when it comes to ecosystems, and with few significant exceptions, none of these conditions apply. Given the fundamental limitation of the earth's arable surface and its crucial function as a collector of sunlight, we are not free to analogously stack such processes. Similarly, anytime the sun doesn't shine "production" halts with no other option. Further, once a plant has germinated photosynthetic growth and respiration cannot be interrupted until natural periods of dormancy are reached or plant maturity--as we define it--has been attained. To do so would result in a total loss. Thus, every component biological process must wait its "natural order." As a result, natural capital cannot be so sequenced and scheduled to even significantly reduce, let alone eliminate, its inherent "inefficiency" at least as seen by short-term economic understanding. In short, nature is overcapitalized and as a result, forests can never be factories. This is another example, perhaps the most significant, why the analogy of capital can be pushed only so far.

## Asset Value Justification in General

Of course, the point is not to just let the future happen, but to avoid difficulty as best we can. While long-standing expectations for future development have certainly assumed that ecosystems would automatically exist to fulfill the hopes we have for our posterity, such continuity can no longer be taken for granted and we must now do more than merely recognize our ethical/moral responsibility to others in the present as well as our posterity. That such ethical or moral considerations must arise in no way implies--at least in our view--that such perspectives are superior to physical considerations as exemplified in the necessary structures of either ecosystems or social systems. Our point is that neither is sufficient on its own account to ensure our survival. Indeed, no action or perspective can do that--humans are inherently fallible but even if they weren't, the physical world would still throw surprises that we could not handle. Both perspectives are enormously useful to inform the other of weaknesses in its ability to cope single-handedly with various realities of human existence.

One way we might approach this conundrum of identifying the unidentifiable is by considering all value bases that underlie why we might value something. By so doing, even if many, perhaps even all such bases, cannot be quantitatively measured, we may more likely appreciate the hazards--ecological, economic, psychological, or sociological--that current actions may entail. And while such appreciation can't guarantee success, the greater caution it might engender may increase our chances. Most important, these other bases of value could provide more robust reasons for considering forests as capital.

### Economic values and the material fabric

The valuations a society imputes to forests, while not determined by it's needs, are heavily influenced by them. And, in turn, such needs structure and are structured by a society's economic and cultural development. Of course, a society's most basic need is to survive. And to the extent that a society is successful in meeting this basic need, perhaps even engendering a "resource surplus," such a surplus can then be directed toward other 'needs' perhaps leading to more than mere survival but to development. But it is in the economic facets of this broader developmental process where economic values have evolved, in a sense as society's endorsement of its members' skill in using resources to meet its material needs. Thus, economic values are only one of many kinds of value that a society needs to develop, and regardless of all these values' functions--that is, all the different roles such values may play in this development--all values eventually lead to actions. And here is the point: every action regardless of its motivation has economic consequences. Economic values, because they arose specifically to use the environment, will entail particularly direct environmental consequences--many potentially hazardous. Among its most important are effects on the integrity of natural systems--a property which economics cannot illuminate by itself.

The increasing attention accorded to natural resource accounting is a direct reflection of its promise to more realistically link economic expectations and performance to an ecosystem's productive capacity in ways that will enable us to extract a sufficiency of economic value while somehow maintaining ecosystem integrity. Harrison (1989), Bartelmus et al. (1992), and particularly Repetto et al. (1987, 1989), have made significant suggestions to this end. In Repetto's evaluations of the Indonesian and Costa Rican economies which are heavily dependent on exporting natural resources, when the forest and agricultural ecosystem capacities producing these exports were examined, net economic productivity--formerly seen as increasing dramatically--was either level or had declined! The reason: conventional measures of economic performance regard ecosystem inputs at zero cost. Ideally, a complete accounting would simultaneously determine the actual value of the income producing capacity of natural capital--which involves the economic values to the present generation; and its potential value--involving the economic value to future generations Economic values are derived from the utilities of individuals now living, and may have little relevance to future generations, because the *future* values--of ecosystem goods, services, functions and unknown potentials--can only be justifiably based on the utility of *future* individuals. Current option and existence values only reflect the willingness of *present* individuals to pay for preserving opportunities for their *own* future as best they can visualize it.

. Unfortunately, as with predicting emergent properties or reversing the irreversible, this is not possible. While we must assume something about the values of future generations, we must not assume too much. We shall return to the question of future generations presently.

Economic values and the social fabric

We have just pointed out that economic values are a basic kind of value grounded in our material necessities; are directed toward adapting to, and in the process, manipulating the environment; and such manipulations entail intrinsically unknowable hazards as exemplified by "damage" to ecosystem integrity. But economic criteria have other limitations. First, the economic value of a forest fails to capture their full value because of limitations in our knowledge about forests--how they function and their myriad connections to survival beyond the immediate commodities yielded. Second, future values will depend on future understanding--hopefully more advanced--not only of the ecosystems from which future demands must be met, but also--and here is a crucial point--of the social fabric within which such values and demands must arise. For the fact is, and in every society, many values and "needs" are often socially constructed rather than irreducible material necessities. It would be especially ironic if, in emphasizing the ecological and economic understanding that must be improved, we neglect equally necessary improvements in our understanding of social motivations on which our survival also rests.

In this light, we must recognize that people value forests for many reasons, not only those reflecting economic need. And such non-economic reasons may nonetheless have economic consequences. Forests are valued as ecosystems that support all life, as resources for our survival, and as places of great symbolic and aesthetic inspiration. Yet even though economic necessity is arguably an imperative of the first order, reflexive, longer-term perspectives made possible by the emergence of human consciousness, and institutionalized in society may prove to be more robust strategies for survival than simply meeting largely short-term basics. We refer to the ability of humans to incorporate reason and experience to evaluate--using many different criteria--the possibilities for unexpected hazards that instinctual tactics have no chance of anticipating. Short term views fall into this category. Such a more "complete" spectrum of values, when integrated in a suitable socialization process, can provide individuals and societies with both the constitutional and institutional support, respectively, for much longer-term views. Especially as compounded by huge populations, it may well be our ability or lack thereof, to integrate--some say to re-integrate--such wider arrays of values that will more likely lead to success in managing the earth's resources sustainably. In short, other non-economic values are just as valid as economic values for considering forests as capital.

A particularly important category of value concerns the importance of forests to the communal dimension of social life. In economics, such communal or societal values are too often seen as simply the aggregated sum of (quantifiable) forest values to its individual members. In its aggregate "sand pile" approach, the only point of reference from which value is derived is in terms of what something does for the 'utility' of individuals. These individually oriented utilities are then 'added up'--and this is another crucial point--it is only at this juncture that society as a point of reference is introduced. But social life is not that simple: Individuals do not 'relate' to society only when their values or preferences are 'added up' with those of others around them. Individuals are part of society from the moment they are born. Indeed, without the socialization processes of culture and language, *they would not develop into individuals at all*. Certainly, individuals are seen to 'value'--i.e., derive utility from--being members of a society. But here society is a 'secondary' point of reference: being a member of society is on a par with any other group one may belong to--e.g., the YMCA. In this view, individual valuers remain ontologically prior to, and somehow *separated* from, society. In contrast, modern sociological theory recognizes individuals as ontologically a *part* of society, who arise if at all, only after a lengthy, uninterruptable, and hazard-filled process of physical development and mental socialization. Thus here too, *society* and *individual* can be seen as another dialectical continuum.

Taken together, narrower economic perspectives--value as only originating in impossibly autonomous individuals, who somehow arose without connections to a necessary and enabling culture and language, and value as limited to only an ecosystem's material commodities without recognizing how its organic integrity contributes to our survival--may well prove fatal. Costanza and Daly (1990) suggest that a *Homo economicus* differing radically from the pure individualist assumed by neoclassical economic theory, could enormously bolster the imperative to consider future generations. They state:

"This broader *Homo economicus* (call him *H-e 2*) to differentiate him from the neoclassical (*H-e 1*) is a person *in community* (our emphasis) rather than a pure individualist. *H-e 2* is also fully informed about how the economy is related to ecosystems and is constituted *in his very identity* (again, our emphasis) by the relations of community with both future generations and other species with whom he shares a place in the sun. *H-e 2* would value natural capital according to its relative long term potential for supporting life and wealth in general. The willingness-to-pay of *H-e 2* (person in community) is hypothesized to be in accordance with this long run capacity to support life and wealth."

Indeed, it is the neoclassical assumption of a utility maximizing *Homo economicus,* allied with the notion that actual human behavior can be reduced to the implicit operation of an economic *calculus*, that while so powerful and useful at one level, is so unrealistic, even destructive when attempting to reproduce the social fabric. Undoubtedly, such communal values exist and the 1992 Environmental Summit in Rio de Janeiro is only one piece of evidence for their emergence not only in small groups but also at the international level. Of course, many important questions remain: By what yardstick might communal values be measured? Whatever the criteria, these must explicitly recognize mechanisms, institutions, and evolutionary processes through which the validity and legitimacy of communal grounds of valuation take their place along side an equally important (but presently oversimplified) instrumental use of nature. At minimum this requires that the significance of forests not only to individual utilities (in terms of their own life histories and prospects) but also to maintaining and reproducing social relations, be the object of every asset valuation method.

Economic values and the ethical, moral, and aesthetic fabric

All the above suggest that assets and their valuation are a much more complex and important notion than generally realized. But if many now recognize that effective forest management requires a multidimensional spectrum of values to integrate presumably objective aspects of the material world with the (perhaps less objective) sociological (Bengston 1993, Iverson and Alston 1993), how can we incorporate such apparently different notions into development objectives? We think the answers lie in combining the material domain of values summarized above with its potentially immaterial aspects. First, as outlined above, we must better integrate the physical and social criteria by which we may most likely achieve material and cultural sustainability. These two areas are sometimes seen as separate, yet both areas are rightly classed as sciences for both deal with different aspects of the material world. And since the reasons for considering forests as natural capital are motivated primarily by the realization that current ecological understanding is materially inadequate, so too should it be clear that a systemic, which is to say, scientific understanding of society is also necessary, of which the economy is only a part. For these two functions of material and social reproduction are inextricably linked in an emergent and evolving material and social world; It is in the social system where major motivations and aspirations to direct these activities must first arise.

But second, no answer will be satisfactory unless our efforts to achieve sustainable development also consider ethical, moral, and aesthetic dimensions however difficult this may be. Such additional considerations are necessary for the simple reason that our material and social science will never be able to catch up with real developments. Again, it is not a question of which viewpoint--material and sociological versus ethical, moral, or aesthetic is superior. None is sufficient by itself and we must supplement our impressive yet insufficient grasp of physical and economic reality with the necessary yet surely problematic perspectives of duty and obligation. In short, while scientific perspectives have dominated recent efforts to understand what sustainability means and will continue to play a major role, the legitimacy--indeed the necessity--for other kinds of value such as ethical, moral, and aesthetic will be increasingly asserted (Andersen 1966, Sankovskii 1992, Sagoff 1988, Callicott 1985, Rolston 1985, Schroeder 1991, Ehrenfeld 1988 and Brown 1984).

## Depreciation, Depletion, and Capitalization

Attention thus far emphasized several problems with *valuing* forests as capital assets. We now consider the extent to which these problems must alter how we apply capital theory's notions of *depreciation, depletion, and capitalization* to marshal the resources for maintaining and reproducing healthy ecosystems. Recall that the definition of capital for our purposes is a produced fund of goods that are themselves used but not consumed in the production of other goods. Such other goods may be stocks of intermediate products, stocks of final products, or new capital funds. Consider briefly the two perspectives from which the value of any capital asset may be examined. While a machine, for example, could be sold in its present condition and thus yield an income to its owner, this is not our concern here. Instead, we are interested in the second perspective: a machine's function as a capital asset in an ongoing production process.

In terms of this ongoing process, a machine's immediate or current value may be regarded as its replacement cost. And yet in its present condition, this cost may well exceed the income to be derived from its sale. This highlights the fact already described, that as we use capital assets, they undergo quantitative and qualitative changes: Even with the best of care capital assets wear out or become obsolete. Such losses in value are termed *depreciation.* And since we assume that the firm will stay in business, this depreciation must be estimated, a portion of gross income in this amount set aside, and eventually expended to repair or renew the asset. This process of repair or replacement is termed *capitalization*.

The effects of utilizing other kinds of assets, on the other hand, are reflected not so much in qualitative changes--as with capital use--but in quantitative reductions in their size due to their actual consumption. As mentioned earlier, raw material stocks such as oil and other minerals are consumed by the production process; and their reduced contributions to the income generating capacity of a firm is reflected not in their less-efficient functioning, but in a physical transformation that can be likened to 'disappearance.' This type of reduction in value--termed depletion--is proportional to the quantitative and permanent reductions in the size of a finite resource. Depletion is analogous to depreciation only in the sense that both represent decreases in present and future value.

In contrast to such finite, exhaustible resources, while the harvests of forests (and other so-called renewable resources) may also reduce stock size, under certain conditions particularly affecting rates of use, such renewable resources have an inherent capacity to replace themselves. In this case, while depletion may be avoided, depreciation cannot. In other words, renewable resource flows may continue only if we ensure that the underlying productivity of the self-organized and self-reproducing process is somehow "maintained." We will return to this question of maintenance later.

Let us now briefly consider forests as both a capital fund and as a stock, and the significance of depreciation when viewed in this manner. As described earlier, at some time in a forest's life a direct income may be obtained by, for example, a timber harvest. For such presently utilized goods and services, the income generating capacity of the ecosystem is (to a greater or lesser degree) realized in the market value of the timber cut. Such a value is also realized by the present generation. In contrast, forests that are not harvested may be regarded as continuing to play their role as capital assets, much as the machine in the ongoing firm, in the following important sense. A sizable but still growing forest's ability to provide timber is both in the present and future. Whether this resource is utilized by either present or future generations--means that these resources may be viewed simultaneously as a final product (i.e., the source of currently existing and immediately utilizable outputs) or as the *means* by which future products may be continually generated--that is, as *capital*. In effect, forest lands possess the ability to appreciate in real value. Two points merit attention. First, forest stock values may appreciate because of increasing exchange and/or use value. The former, termed *price appreciation,* occurs when, as forests becomes more scarce, prices of the goods and services they generate also increase. Since no increase in physical income flows has occurred, we are interested in the second: *Real* or *Use-appreciation* occurs when potential incomes are turned into actual incomes or when resource quality and quantity increases when recognizing ecosystem features--for example, increased demand for forest recreation, recognizing the values of protected forest properties, and increased water quality due to less pollution. Second, real value increases (measured at time $t$+1) must also reflect the income that could have been derived at time $t$ by liquidating the forest. This income was foregone when the forest was allowed to function as capital--i.e., to produce more of itself. Such income foregone is determined by the product of market value at time $t$, times the interest rate compounded over the period $t$+1.

A similar logic applies to depreciation of forests as capital assets. First, if a forest's actual generation of a good--that is, its supply--increases without a shift in demand, per unit price may decrease enough to decrease the total priced value of the good. And while income may be redistributed among various groups as a result of such a change, whether real welfare has improved requires a more detailed examination of this redistribution. This situation parallels the example of price appreciation noted earlier. But of more immediate concern here, if the capital stock of a forest ecosystem is materially depleted, both its current and future income potentials decrease. The extent of this decrease, and in effect the severity of the problem, depends on what is envisioned as actually decreasing; that is, what values (reflected in income-generating capacity) are reduced; and these values depend on what goods and services the forest is envisioned as capable of producing. In most cases, depreciation is limited to wear and tear on the capacity to produce commodities that people are aware of and desire: An important implication is that if there is no demand for that which is lost--no loss in economic value would be recognized nor depreciation reserved from consumption! This problem will inevitably occur when not all of the functions which an ecosystem's income producing capacity must serve, have been identified--i.e., when a currently unknown part of its output may be needed for its own replacement and development. As a result, we would overestimate the productive capacity of forest ecosystems, and if so, long-term forest productivity, at least as now understood, would be unlikely. Replacing diverse natural forests with single species plantations having simplified--and perhaps more unstable--ecological functions fall in this class.

This problem is also reflected in the measures used to assess a forest's (fund/stock) sustainable income producing capacity such as its *size* expressed in area or volume. But as James et al. (1989) observed, this indicator is not robust: In some cases, sustainable yields may be enhanced by increasing stock size--for example, when a forest is established where none existed. In other instances, ecologically appropriate harvests of old, slower growing stands followed by immediate reforestation may reduce stock size but increase future yields. A forest's income producing capacity also depends on its age-class distribution and other structural details--not least of which is its spatial or hierarchical interconnections with other forest components or other ecosystems. For example, a conifer plantation could have the same spatial and age class distribution and volume as that of a natural forest with many species, but its sustainable net income capacity may well be reduced if all the costs of maintaining the less diverse system were considered. Similarly, the function and efficiency of a farm shelter-belt system depends more on its arrangement with respect to wind direction, planting patterns, tree and shrub growth form, and its linkage to a system of shelter-belts across a landscape, than on its individual area or volume.

Returning to the central problem of maintaining an ecosystem's productivity, from Hicks' perspective, forest capital can be maintained or increased via a process of capitalization which would invest the depreciation allowances in new or restored capital. Capitalization might consist of investments to increase forest area or density, or by investments to improve wood or water utilization, to enhance the stability of ecosystem structures, or to develop more efficient and durable patterns of land use. But significant difficulties arise because the capitalization process is unavoidably biased against its potential or future capacity. Only the depreciation of actual capacity would be a relatively straightforward matter. Further, even if depreciation were realistically estimated and feasibly reserved--and as should be evident, such tasks are by no means simple--to what extent could we effectively expend such allowances to maintain or restore an ecosystem's income producing capacity? What level of forest use for our needs could be sustained while adequately ensuring for its recapitalization? Further, such methods imply reversible processes and in certain locales or after certain practices reversal may not be possible. And if we cannot restore a previous system, what are the altered system's new possibilities?

As a result of all these concerns, and of course, when we have the room to maneuver, passive capitalization strategies may be our safest option. Instead of problematic *ex post* investments to mitigate damage, we may be better off limiting harvests or other uses so as to leave the ecosystem with enough income--or its equivalent in ongoing structures and processes--to maintain itself. After all, one might say--and not so metaphorically at that--while we do not yet know how an ecosystem maintains itself, the ecosystem does. To the extent that we can stay out of "its" way, we might sometimes be better off.

Thus far, we have raised key problems in considering forests or other ecosystems as natural capital. And while our ecological understanding has advanced tremendously, it is safe to assert at this point that it is currently not up to the task even if we have little choice but to continue current practices. In short, while capital theory's notions of depreciation, depletion, and capitalization offer important perspectives for operationalizing our attempts to manage forest ecosystems, considerable difficulties arise because of the coevolving thermodynamic nature of ecosystems and social systems. Constraints imposed by the laws of thermodynamics, as well as the patterns of resource use resulting from societal attitudes towards, and interactions with, natural systems imply that *any* use of renewable resources may have lasting and unexpected effects. Thus, the "reproduction" of neither system can be taken for granted--even perhaps, at very low levels of interaction. Based on this by no means exhaustive summary, we now briefly consider a few implications for any attempt to develop more realistic resource accounts.

## Implications for Forest Resource Accounting

### Linking sustainable use and economic need

Thus far, we have described a number of conceptual and evaluative aspects of forests as natural capital. We pointed out difficulties in determining and adjusting economic uses of forests to their sustainable potentials. While capital provides a broadly integrative idea in regard to functional requirements of reproducing ecosystems, economies, and societies, certain limits in its applicability were identified. First, due to the evolving nature of both natural and social systems, including the irreversibility of many constituent processes, we cannot steer them in quite the way scientists and foresters have assumed. Thus, any capital account, while intended to link economic action and forest ecosystem integrity, may provide only limited indications of sustainable output levels.

Second, all forest values are social constructions based on evolving material understanding, as well as world-views and expectations. Yet because such expectations may be unrealistic while at the same time strongly influencing our concrete actions, they may lead to actions which irreversibly foreclose future possibilities. Thus we must recognize that any set of qualitative or quantitative measures are tentative in another sense: Our concern is not so much that current forest valuations do not adequately account for wear, tear, and obsolescence--this is inevitable--but that current actions may result in destructive consequences. That is, our concerns aren't so much about "sins of omission", as about "sins of commission." This should further bolster an imperative for caution.

Third, we described economic action as rooted in largely instrumental and individualistic values, and highlighted the limitations of such values to meaningfully address collective concerns such as ecosystem or social system stability and integrity. The problem here is not so much that an economic perspective embodies no values of a collective nature. Such a view is mistaken when we recognize that a 'good society' from an economic perspective is instituted in social arrangements that allow individuals the freedom to pursue their own legitimate interests. That is, such a society entails a minimum but necessary legal framework to ensure basic individual rights to all. Thus, such a society is seen to be the collective reflection of the basic value of human freedom (Wuthnow 1987). Nor does the difficulty refer to the contribution of an economic perspective as a central value of democratic societies; but rather that, if the driving force for individual actions is only definable in terms of individuals pursuing their own interests which have no necessary relationship to the interests of others--then no notice can be taken of the fact that individuals are simultaneously members of both social communities and the natural world. If this difficulty were more widely appreciated, then communal values--reflecting individual membership in both social and natural systems--would be accorded their proper status. In the process of pursuing justifiable individual desires, we must not forget the ecological and social fabric that gives rein to a more mature deployment of collective experience and wisdom.

In light of the above, it is not surprising that as we move from theory to practice, how to measure the condition of forest capital in order to maintain its "income" producing capacity is not clear. The following briefly considers how we might address this problem via a system of three interrelated natural resource accounts to track: (1) actual incomes, (2) potential incomes, and (3) their linkage through appropriate estimates of depreciation to re-capitalize renewed or adequately protected natural capital.

A system of Actual, Potential, and Linkage accounts

Based on our discussion of the duality of forest incomes, two complementary natural income accounts are implied (Figure 2). First, considering the welfare of the present, natural income refers to the stocks of goods and raw materials consumed or ecosystem capital services used, and would be recorded in a set of *Actual Income Accounts* to physically and monetarily track resource stocks and flows, as well as capital asset conditions. Existing resource accounts emphasize some of these features, such as timber volumes and prices, but could be broadened substantially to include other economic resources that sustainable resource management efforts require--at least as currently envisioned. Actual income for certain resources such as wood, may be more clearly tied to specific housing and paper requirements based on population and per capita consumption projections in particular markets. But while *the Market* is a very powerful device for allocating resources and stimulating innovation, we can no longer fall back on the wide-spread ideology that markets can somehow side-step the laws of thermodynamics through technical advance. Taking nothing for granted, we may avoid incomplete abstractions so characteristic of current accounts. Another addition might be to more carefully track tangible and intangible public assets embodied in infrastructure such as schools, universities, and research facilities that focus on natural resources.

Second, considering future welfare, natural income refers to both the potential goods and services that might be discovered and delivered as well as those now already known to exist and therefore potentially available for consumption. Ideally, this set--termed the *Potential Income Accounts*--would track the stocks and flows of all potential life supporting goods, as well as the funds of natural capital services generated by or attributed to ecosystems, regardless of whose welfare they may benefit. Yet we mentioned the paradox of attempting to measure such potentials since these may only be realized and thereby valued in this limited sense by future generations. However, there seems little argument that we in the present, have some responsibility to carry forward, as best we can, the current mix of forest ecosystems, perhaps even enhancing them as foresters have for a long time claimed. Of course, the extent of this responsibility is another matter. Such potential accounts would attempt to measure the qualitative and quantitative but non-economic aspects of current ecosystems that we might plausibly link to future ecosystem productivity and stability. Most obvious would be inventories of many currently *non*-economic plant and animal species, and other non-economic qualities and quantities of forest land, water, and air. A very difficult yet important task for the ecologists, such accounts might consist of indices of "healthy" ecosystem structures and functions that underpin economic productivity and ecological stability. Recent attempts to define and operationalize measures of biodiversity and other indications of ecosystem "health" and integrity come to mind (Costanza et al. 1992).

Something is missing, however. We also need to realistically link today's real demands and options with our estimates of tomorrow's potentials. For while future forest potentials may well be huge, how can we compare mere projections to immediate and compelling needs? Thus, to the extent that we accept our responsibility towards our posterity, a third set of accounts is required which at least attempt to put future desires in perspective with current needs and abilities. Such a set of *Linkage Accounts* would attempt to measure the costs to the present generation of it's choices to fulfill its various and "self-imposed" obligations to the future. Such cost accounts could include: (1) actual depreciation reserves considered necessary to maintain future forest productivity. Moneys held back from gross revenues for state-of-the-art silvicultural investments is a good example; (2) actual charges to repair or replace already damaged or destroyed forest assets that the present now feels obligated to reproduce as best it can. Restoring a wetland or reestablishing viable peregrine falcon populations are examples; (3) actual charges to prevent forest damage, whether related to our actions or to natural forces. These might support research to develop safer and more ecologically relevant pest controls, or lighter, more ecologically benign harvest machinery. Moreover, ecosystem research may reveal certain practices to be unacceptable and that steps to prevent their damaging consequences would need to be incorporated within existing legislative and/or regulatory practices; and (4) pure opportunity costs--the economic benefits foregone by the present in order to preserve some unique natural asset deemed irreplaceable. Public decisions to set aside spectacular forests and other scenery are examples. In a real sense, such linkage accounts would at least partially operationalize existence, option, and bequest values. In short, such linkages can be considered not as the cost of ensuring sustainable forest development, for this cannot be guaranteed, but as the opportunity costs the current generation is willing to forego in order to redeem as best it can, such self-imposed obligations to the future.

An additional conundrum would complicate an already difficult task: forest resource accounts would vary by ecoregion and by cultural expectations. Figure 1 defined Unused Income as a form of potential income derivable from goods and services which have been discovered but not utilized because of technical, economic or social barriers. Such barriers would vary across the globe. For example, forest recreation opportunities, which may be in high demand in industrialized, urban areas, usually have a low priority in developing regions. The marginal rate of return on investments to use and maintain such capacity is virtually zero to the developing area as long as there are more compelling needs. How could such a system reflect developmental differences between and within nations, thereby bolstering the real (often denied or seen as too abstract) communal justifications that tie all regions and all peoples together?

A regional system of inter-locking resource accounts

From our discussion of the unique features of every society and the unique ecological features where they reside, it should be clear that any system of resource accounts--whether for forests or more encompassing ecosystem aggregations--must literally be constructed from the ground up--site by site and community by community. That is, land management is not abstract but involves real economic options and real resource impacts on real citizens, owners, and managers with real cultural differences. But, if we are ultimately to use our globe's limited resources sustainably while ensuring an equitable distribution of these resources among its peoples and across generations, it is urgent that we develop a coherent system of natural resource and environmental accounts to link ecosystem productivity and health with realistic economic outputs, thereby maintaining future possibilities around the globe.

For example, recent agreements such as NAFTA (North American Free Trade Agreement) to more "fairly" regulate trade are based primarily on arguments for economic efficiency. Such agreements could and should be expanded to more explicitly include principles consistent with sustainable resource management and social equity. But to do so would require a set of accounts that force trading partners to face the ecological and social consequences of their consumption where ever these occur. Based on such accounts, developed and developing countries might jointly reduce avoidable depreciation or depletion of their natural capital and resource stocks, in the process preserving joint future options. For in general, to the extent that basic needs of developing regions nations are met--and hopefully surpassed--it is more likely that they will also recognize a wider variety of essential ecosystem goods and services that would redound not only to their benefit but to that of the entire world. Such global expressions of concern would not be based entirely on altruism--however important such motivations might be--for such connections are real and material.

To the extent that these goods and services are clearly recognized as contributing to national income and welfare, increased investment in and replacement of natural capital will be more likely. Such accounts linked to the United Nation's System of National Accounts could be the basis for building environmentally sound and socially just trade policies and norms. However, since every economy is only one facet of an over-arching social system, such a system of ecological-economic accounts would only be a subset of a larger social accounting system that might one day emerge. The latter might be based on more broadly justified criteria to reflect communal and collective justifications as well as an individualistic and instrumental understanding of Nature.

## Summary

On-the-ground forest management practices increasingly recognize (1) the irreversibility of many natural processes that characterize ecosystems, (2) at least a crude distinction between actual and potential forest ecosystem outputs in efforts to maintain biodiversity and other ecosystem features, and (3) the need to consider a multidimensional value spectrum. From early exploitation through the conservation movement, to Sustained Yield/Multiple-use, New Perspectives, and now on to a paradigm of Ecosystem Management, awareness of the central and usually irreplaceable role of natural systems in all aspects of human life is taking hold (Interagency SEIS Team 1993, USDA Forest Service 1992, USDA FS Eastern Region, Northeast and North Central Forest Experiment Stations, 1992). But such a recognition--important as it is--cannot be sufficient. More explicit and practicable forest resource accounts and measures embodying these ideas are required if we are to maintain forest capital to the broadest extent possible. In short, achieving sustainable forest resource use requires that we make full use of forest capital through a combination of ecological, economic, and social practices that avoid as best we can, obtaining forest products and services at the expense of long term ecological health and productivity. A system of three distinct forest asset accounts may prove useful: one to measure the actual capacity to meet the needs of the present, a second to estimate the potential capacity to meet the needs of the future, and a third to estimate the opportunity costs of linking the first two. The Actual capacity account would reflect the relation between forest capital and current welfare. The Potential capacity account would reflect difficulties of maintaining forest ecosystem capital for future welfare. The Linkage account would tie real and current sacrifices to future hopes and aspirations. Such a system is required for three major reasons; (1) to monitor and maintain the irreplaceable life-support functions of ecosystems; (2) to more realistically and efficiently allocate the consumable natural capital to the economic system; and (3) to more equitably and legitimately meet the needs of individuals and societies. With such a system of accounts, the ecological, economic, and broader social basis of sustainable resource use would be more firmly established.

Our discussions made several appeals to caution; emphasizing the need to take full responsibility for the social and ecological consequences of current economic activities. Up to now, such imperatives to recognize broader responsibilities have almost without exception, been thought unnecessary in the face of impressive benefits from, and universal appeal of almost 300 years of economic expansion. And after such a long time of viewing resources as unlimited and development as most likely to be achieved by the largely absolute private ownership of resources, maintaining or liquidating one's capital is widely considered a matter of individual choice. However, it should now be clear that when ecosystems are at risk, such freedom is not absolute but is constrained by real material and thermodynamic limits, by real connections with, and thus, obligations to others, and by the need to preserve future possibilities in the face of what may turn out to be at best unsustainable, and at worst fatal resource demands and impacts. Individual freedom--important as it is as an ideal--must be balanced with concerns for the common good--however people come to define such a good within these emerging and larger ecological and social realities. If we, as foresters who understand forests best, can see these limitations clearer, our efforts to maintain the productive capacity of forests may be more effective. With such an awareness--perhaps even raised to the level of a universal imperative--individual and collective goals could then encompass not only those forest goods and services directly necessary for human survival, but also the analogous "goods and services" previously thought sufficient for forest ecosystems to automatically maintain themselves. Our concerns about the continued productivity and functioning of forest ecosystems might then more realistically encompass their many components, structures, and processes as they all interact to maintain an evolving yet ongoing system. This is really what is meant by sustainability.

## References

Ahmand, Y. J., S. El Serafy and E. Lutz (eds.). 1989. Environmental accounting for sustainable development. World Bank, Wash. DC,. 100 p.

Anderson, B. M. 1966. Social value. Reprints of economics classics. Augustus Kelly. New York. 204 p.

Anon. 1992. "Ask a silly question": Contingent Valuation of Natural Resource Damages. Harvard Law Review. 105(8): 1981-2000. June.

Bartelmus, P. 1989. Environmental accounting and the system of national accounts. P. 79-87 in Ahmand, Y. J., S. El Serafy and E. Lutz (eds.). Environmental accounting for sustainable development. World Bank. Wash. DC,. 100 p.

Bartelmus, P., E. Lutz, and S. Schweinfest. 1992. Integrated Environmental and Economic Accounting: A Case study for Papua New Guinea. Environment Working Paper No. 54. Environment Department, The World Bank, Wash. DC,.

Bengston, D. N. 1993. Changing values and ecosystem management. Society and Natural Resources, 1993. (Forthcoming)

Bliss, C. J. 1975. Capital theory and the distribution of income. Amsterdam: North Holland Pub. Co. 378 p.

Braden J. B. and C. D. Kolstad (eds.) 1991. Measuring the Demand for Environmental Quality. Amsterdam: North Holland Pub. Co. 370 p.

Bradley, D. P. and B. J. Lewis. 1992. Ecological economics: Integrating natural and social dimensions. Journal of Forestry. 90(2):30-33.

Bromley, D. W. 1991. Environment and Economy: Property Rights and Public Policy. Cambridge USA: Blackwell. 247 p.

Brookshire, D., L. Eubanks, and A. Randall. 1983. Estimating option prices and existence values for wild life resources. Land Economics, 59: 1-15.

Brown, T. C. 1984. The concepts of value in resource allocation. Land Economics. 60: 231-246.

Callicott, J. B. 1985. Intrinsic value, quantum theory, and environmental ethics. Environmental Ethics. 7(11): 257-275.

Cicchetti, C. J. and L. L. Wilde. 1992. Uniqueness, Irreversibility, and the Theory of Nonuse Values. American Journal of Agricultural Economics. (1992): 1121-1125.

Ciriacy-Wantrup, S. V. 1963. Resource Conservation: Economics and Policies. Berkeley: University of California Press. 395 p.

Clark, C. 1976. Mathematical bioeconomics: The optimal management of renewable resources. New York: John Wiley and Sons. 352 p.

Costanza, R., and H. Daly. 1990. Natural capital and sustainable development. P. 87-110 in Proceedings: Ecological economics: Its implications for forest management and research. April

1990. St. Paul, MN. Swedish University of Agricultural Sciences, Garpenberg. Research Notes No. 223. 239 p.

Costanza, R., B. Norton, and B. Haskell (eds). 1992. Ecosystem Health: New goals for environmental management. Island Press, Wash. DC. 269 p.

Cummings, R., D. Brookshire, and W. Schulze. 1986. Valuing Environmental Goods: A State of The Art Assessment of the Contingent Valuation Method. Totowa: Rowman and Allenheld. 270 p.

de Groot, R. S. 1992. Functions of Nature: Evaluation of nature in environmental planning, management and decision making. The Netherlands. Walters-Noordhoff. 315 p.

Dixon, J. A. and M. M. Hufschmidt. (eds.) 1986. Economic Valuation Techniques for the Environment: A Case Study Workbook. Baltimore: Johns Hopkins University Press. 203 p.

Ehrenfeld, D. 1988. Why put a value on biodiversity? P. 212-216 in Wilson, E. O. (ed.). Biodiversity. National Academy Press. Wash. DC,.

El Sarafy, S. and E. Lutz. 1989. Environmental and resource accounting: an overview. P. 1-7 in Ahmand, Y. J., S. El Serafy, and E. Lutz (eds.). Environmental accounting for sustainable development. World Bank. Wash. DC,. 100 p.

El Sarafy, S. 1991. The environment as capital. Chapter 12, P. 168-175 in Ecological economics: The science and management of sustainability. Robert Costanza (ed.). Columbia Univ. Press. New York. 525 p.

Gleick, J. 1988. Chaos: Making a new science. London: Heinemann. 352 p.

Georgescu-Roegen, N. 1971. The Entropy Law and the Economic Process. Harvard Univ. Press. Cambridge. 457 p.

Harrison, A. 1989. Introducing natural capital into the SNA. p 19-25 in Ahmand, Y. J., S. El Serafy and E. Lutz (eds.). Environmental accounting for sustainable development. World Bank, Wash. DC,. 100 p.

Hausman, J. (ed.) 1993. Contingent Valuation: A Critical Assessment. New York: North Holland. 503 p.

Hicks, J. 1946. Value and capital: An inquiry into some fundamental principles of economic theory. Oxford Univ. Press. 340 p.

Hicks, J. 1974. Capital controversies: ancient and modern. American Economic review. 64: 301-316.

Hufschmidt, M. M., D. E. James, A. D. Meister, B. T. Bower and J. A. Dixon. 1983. Environment, Natural Systems and Development -- An Economic Valuation Guide. Baltimore: Johns Hopkins University Press. 338 p.

Interagency SEIS Team. 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. USDA FS, USDC NMFS, USDI BLM, USDI FWS, USDI NPS, and EPA.

Iverson, D. C. and R. M. Alston. 1993. Ecosystem-based forestry requires a broader economic focus. Journal of Sustainable Forestry. 1(2):x-.

James, D. E., P. Nijkamp, and J. B. Opschoor. 1989. Ecological sustainability and economic development. P. 27-48. in Nijkamp, P. and F. Archibugi. (eds.). Economy and ecology: Towards sustainable development. Kluwer Academic Publishers. Boston. 348 p.

Johnson, R. L. and G. V. Johnson (eds). 1990. Economic Valuation of Natural resources: Issues, Theory, and Applications. Boulder: Westview Press.

Kahneman, D. and J. L. Knetsch. Valuing Public Goods: The Purchase of Moral Satisfaction. Journal of Environmental Economics and Management. 22(1992): 57-70.

Kneese, A. V. 1984. Measuring the Benefits of Clean Air and Water. Washington, D.C.: Resources For Future.

Kopp, R. J. and V. K. Smith. 1992. Valuing Natural Assets: The economics of natural resource damage assessment. Washington, D.C.: Resources for the Future. 358 p.

Krutilla, J. V. 1967. Conservation reconsidered. American Economic Review. 57(1967):777-806.

Loomis, J., G. Peterson, and C. Sorg. 1984. A field guide to wildlife economic analyses. Transactions of the North American Wildlife and Natural Resource Conference, 49: 315-324.

Mitchell, R. C. and R. T. Carson. 1989. Using Survey to Value Public Goods: The Contingent Valuation Method. Washington, D.C.: Resources for the Future.

Norton, B. 1992. Sustainability, human welfare, and ecosystem health. Environmental Values .1(1992): 97-111.

Peskin, H. M. 1989. A proposed environmental accounts framework. P. 65-78 in Ahmand, Y. J., S. El Serafy and E. Lutz (eds.). Environmental accounting for sustainable development. World Bank, Wash. DC,. 100 p.

Peskin, H. M. 1991. Alternative environmental and resource accounting approaches. P. 176-193 in Ecological economics: The science and management of sustainability. Robert Costanza (ed.). Columbia Univ. Press. New York. 525 p.

Peterson, M. J. and T. R. Peterson. 1993. A rhetorical Critique of "non market" economic valuations for natural resources. Environmental Values . 2(1993): 47-65.

Randall, A. & J. R. Stoll. 1983. Existence value in a total valuation framework. P 265-274 in Managing air quality and scenic resources at national parks and wilderness areas. Rowe, R. D. & L. G. Chestnut (eds.). Boulder: Westview Press. 314 p.

Randall, A. 1991. Total and nonuse values. p 303-322 in: Measuring the Demand for Environmental Quality. J. B. Braden and C. D. Kolstad (eds.) Amsterdam, The Netherlands: North Holland.

Redclift, M. 1993. Sustainable development: Needs, values, rights. Environmental Values 2(1993): 3-20.

Repetto, R., M. Wells, C. Beer, and F. Rossini. 1987. Natural resource accounting for Indonesia. World Resources Institute. Wash. DC,.

Repetto, R., W. Magrath, M. Wells, C. Beer, and F. Rossini. 1989. Wasting Assets: Natural resources in the national income accounts. World Resources Institute. New York. 69 p.

Rolston, H. III. 1985. Valuing wild lands. Environmental Ethics. 7(1):23-48.

Sagoff, M. 1988. The Economy of the earth: Philosophy, law and the environment. Cambridge Univ. Press. New York. 271 p.

Sagoff, M. 1993. Environmental Economics: A Epitaph. Resources. Spring, 1993, No. 111: 2-7. Washington, D.C.: Resources For The Future.

Sankovskii, A. 1992. Toward evaluation of natural objects. Environment Management. 16(3): 283-287.

Schroeder, H. W. 1992. The spiritual aspect of nature: A perspective from depth psychology. P. 25-30 in Proc. Northeast Recreation Research Symposium, April 1991, Saratoga Spring, NY. USDA For. Serv. Gen. Tech Rep. NE-GTR-160.

Schumpeter, J. 1954. History of Economic Analysis. Oxford University Press, New York. 1260 p.

Shultz, A. M. 1967. The ecosystem as a conceptual tool in the management of natural resources. p 139-161 in: Ciriacy-Wantrup, S. V. and J. J. Parsons. (eds.) 1967. Natural Resources: Quality and Quantity. Berkeley: University of California Press. 217 p.

Soddy, F. 1933. Wealth, virtual wealth, and debt: A solution to the problem. E.P. Dutton, New York. 320 p.

Stoll, J. and L. Johnson. 1984. Concepts of value, nonmarket valuation, and the case of whooping crane. Transactions of the North American Wildlife and Natural Resource Conference, 49: 382-393.

Tietenberg, T. 1988. Environmental and natural resource economics. Scott, Foresman and Co. Glenview, IL. 559 p.

USDA Forest Service. 1992. Proc. Taking an Ecological Approach to Management. Salt Lake City, UT, April 27-30, 1992. WO-WSA-3. Wash. DC,. 241 p.

USDA Forest Service: 1992. Ecosystem Management Strategies for Northeastern and Midwestern National Forests: A Report to the Chief of the Forest Service. Eastern Region, NE For. Expt. Sta. 24 p.

Walsh, R., J. Loomis, and R. Gillman. 1984. Valuing option, existence, and bequest demands for wilderness. Land Economics, 60: 14-29.

Weisbrod, B. A. Collective-Consumption Services of Individual-Consumption Goods. Quarterly Journal of Economics. 78(1964): 471-477.

Wuthnow, R. 1987. Meaning and moral order: Explorations in cultural analysis. Berkeley. University of California Press. 435. p.