Economic Issues in Ecosystem Management: An Introduction and Overview

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Ecosystem management may extend multiple use management, where economists identify and value a complex mix of ecosystem outputs. The dominant theme in conservation biology favors "safe minimum standard" (SMS) constraints on ecosystem attributes, which respond to complex and purely uncertain ecological knowledge and lead economists toward valuation questions that identify "tolerable" constraints. A hierarchical SMS constraint raises substitution possibilities among ecosystem-level components. Economists may identify unavoidable resource tradeoffs, such as in allocating land among elements of a reserve network, particularly when ecological wealth differs among geographically dispersed human communities. Economic and ecological ironies obfuscate intuitive contributions to ecosystem management policy.

Ecosystem management is a concept for or approach to natural resource stewardship, use, or conservation that remains one of the vaguest ideas or mandates of the decade (Mendelsohn 1995; Sedjo 1995a,b, 1996a; Stanley 1995). For the present discussion, *ecosystem management* refers to natural resource management that influences human decisions in using ecological resources, especially land, while striving to recognize "all" the implications of human decisions on the functioning and condition of an ecosystem. Policy or regulation to foster ecosystem management arises from a broad shift in social values toward natural resources (Bengston 1994), from a government response to this shift in values and the judicial manifestations of these public preferences (Flick and King 1995), and, significantly, from the rise and popularity of conservation biology as a science with a "mission . . . to conserve as much of global biodiversity as possible" (Noss and Cooperrider 1994, pp. 84–85). These observations may indicate that ecosystem management is motivated largely by factors other than public preferences for ecosystem attributes per se. Advocates, especially conservation biologists, admonish managers to make concern for "native ecosystem integrity" (Grumbine 1994, p. 31) or the condition or health of the ecosystem (Comanor 1994; Franklin 1989; Gillis 1990; Sedjo 1995b) their primary duty. Ecosystem management, whether as a (vague) objective, an approach, or a philosophy, is likely to affect the fundamentals of environmental management and protection decisions, at least in the United States, for the foreseeable long run.

The vagueness arises for several reasons. First, ecosystem management may become operational in different ways for different natural resource management entities. Second, many, or most, of the proponents of ecosystem management write from a field, like ecology or conservation biology, that does not, necessarily, concentrate on approaches to decision-making or choice, or does not address well the role that public preferences or economics might play (see, for example, Grumbine 1994; Noss and Cooperrider 1994). Indeed, Grumbine's survey of the literature indicates that the areas of greatest weakness include human issues related to changing organizational (agency) structure and the complexities of integrating a diverse and complex mix of human values. Moreover, Grumbine found existing contributions to resolving these human issues to show a weak understanding of the scientific rationale, or conservation biology, behind ecosystem management: interdisciplinary isolation inhibits integration of decision

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science. All of these vagaries, plus the likely longevity of ecosystem management in environmental policy, raise both the opportunity for and the importance of economists as contributors to understanding the implications of ecosystem management.

Therefore, my purpose here is to provide a broad overview of what ecosystem management means to different proponents, to identify some approaches that economists might consider as part of ecosystem management, and to suggest some intuitive and inescapable concerns that economists could elucidate to policy analysts and proponents from other fields. My intent is to provide a wide discussion of issues, yet I know that this discussion is illustrative rather than a complete enumeration of the economic issues outstanding. The paper does not attempt to provide "what is known about the economics of ecosystem management"—the answer would be "not terribly much." Rather, this paper concerns "what could or ought to become known" about the economic implications of ecosystem management. Throughout, I draw heavily on the literature associated with management of forest ecosystems, but the discussion applies more broadly than to forests alone.

Ecosystem Management According to Many

Ecosystem management is a rather vague term, but in reviewing the literature, one concludes that its motivation, as well as its meaning within the last ten years, relates to a belief by proponents that all use of ecosystems to provide human goods or services "should" be given second priority to managing for the "natural condition" or "health" of the ecosystem. For example, Grumbine offers a working definition:

> Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term. (1994, p. 31)

By comparison, Noss and Cooperrider define ecosystem management as follows:

> Any land-management system that seeks to protect viable populations of all native species, perpetuate natural-disturbance regimes on the regional scale, adopt a planning timeline of centuries, and allow human use at levels that do not result in long-term ecological degradation. (1994, p. 391)

Human uses are clearly secondary, while the whole ecosystem perspective is somewhat clear.

Sedjo (1995a,b, 1996a) points out that nothing in ecosystem management literature or in official policy, at least for the U.S. Forest Service, clearly identifies what condition is targeted or is acceptable: proponents advocate managing for some earlier-than-modern condition of ecosystems, but this leaves an apparent arbitrariness concerning questions as to whether this "earlier condition" relates to pre-European settlement, or simply to the conditions that existed in 1800, or to some other ecological condition. The operational objective remains elusive and, in fact, may vary with the agent who interprets the objective for a specific region.

Ecosystem Management as Broader Multiple Use Management

Economists (Mendelsohn 1995; Sedjo 1995a,b, 1996a) have speculated that ecosystem management is simply an extension of multiple use management, by extending the traditional list of market and nonmarket goods and services—timber, range, wildlife, recreation, water yield, and others—to include a measure of ecological health and quality. In this case, the role of ecologists is to provide a model of what multiple outputs may derive from various management plans. The ecological model becomes a production function upon which economists build a multiple use, economic optimization model (Mendelsohn 1995). The new ecosystem management–multiple use objective function would incorporate all aspects of the ecosystem, including viable populations of all species, natural disturbance patterns and mechanisms, and a time frame that allows managers to mitigate human impacts on an evolutionary scale.

Let us reflect a moment longer on the comprehensiveness of this objective. Here, the term "all species" includes not only macrofauna like birds and mammals, but other vertebrates like reptiles and amphibians, and invertebrates like insects, parasites, and bacteria, not to mention plant species of all sizes and roles, again including parasites and microflora (Noss and Cooperrider 1994; Windsor 1995). In addition to a comprehensive concern for biodiversity, the ecosystem management objective weighs the occurrence of natural disturbances or simulated natural disturbances as well as landscape patterns and linkages among spatially distributed habitat types, plant community types, and successional stages or ages.

In applications, analysts may fold these many dimensions of ecological diversity into a single or small collection of convenient diversity indices (Holland et al. 1994; Hunter 1990; Niese and Strong 1992). While simplifying the analytical task, this approach imposes a side effect that the index(es) of record may result in management bias away from ecosystem dimensions (species; landscape structural attributes) that are not well correlated with the chosen index(es) (Noss 1990). Judicious choice of the index(es) may ameliorate such biases because some indices may be well correlated, such as the correlation between bird species diversity and the diversity of vertical forest structure (MacArthur and MacArthur 1961). However, a focus on vertical structure deemphasizes horizontal structure, which may permit managers to create a landscape of small forest patches that are relatively unsuitable for birds requiring expansive forest interiors.

Of course, this complex task is simplified further if ecosystem attributes may be identified as either outputs providing utility or inputs needed to create desired outputs (Crocker and Tschirhart 1992; Mendelsohn 1995). Then management still derives value from ecosystem attributes that provide no utility directly, because some of these attributes are critical inputs to the system. For example, mosquitoes are unlikely to provide direct (positive) utility to people, yet they may have a net positive value derived from their role as a food source to drive aesthetically pleasing acrobatics of Tree Swallows (*Iridoprocne bicolor*).

The view that ecosystem management simply expands the multiple use objective function is comforting and convenient. When correct, the view implies that economists need focus only on the valuation tasks for market and nonmarket goods and services, although these applied valuation studies may need to take a more holistic account of services that ecosystems provide (Bergstrom and Loomis 1995). This multiple use approach may well be valid for many applications, because legal mandates for multiple use management on public land remain in place (Flick and King 1995; Franklin 1989; Sedjo 1995b, 1996a; Stanley 1995). However, there is clear policy support for the scope of multiple use management for public lands to extend across a whole ecosystem, potentially well beyond the legal boundaries of public land reserves (Comanor 1994; Franklin 1989; Noss and Cooperrider 1994; Sample 1994; Sedjo 1995a,b; Swallow and Wear 1993). This scope for ecosystem-based management raises some potentially complex issues for economists, to which we return below.

Ecosystem Management as a Constraint

The idea that ecosystem management simply extends the multiple use approach, while probably valid in some cases, clearly violates the intent of many proponents and possibly overlooks the scientific rationale—or at least the rationale of mission-oriented conservation biologists. The conservation-biological rationale for ecosystem management as policy lies in a fundamental lack of faith that humans are capable of identifying and understanding all the ecological effects of human choices and, simultaneously, the rationale lies in a hypothesis that loss of ecosystem health or resilience may not be characterized by marginal impacts; catastrophic collapse of the ecosystem is hypothesized as a near certainty if social decisions continue to ignore ecosystem health and biodiversity (Arrow et al. 1995; Franklin 1989; Gillis 1990; Holling and Meffe 1996; Noss and Cooperrider 1995; Stanley 1995). This view advocates an emphasis on protection, maintenance, or restoration of healthy and productive ecosystems, rather than emphasizing human uses, by determining constraints on decisions intended to enhance human welfare.

Because ecology is not particularly well suited to prediction, production relationships may be highly or purely uncertain, and many examples exist for which well-considered management decisions created substantial unintended negative consequences (Arrow et al. 1995; Holling and Meffe 1996; Stanley 1995). As a response to ubiquitous uncertainty, this approach may have operational merit in the form of constrained optimization (Franklin 1989; Gillis 1990; Iverson and Alston 1993; Sample 1990). A constrained optimization approach allows managers to identify goals for ecosystem attributes in the form of constraints and then evaluate the shadow cost of meeting those constraints, in terms of those goods and services for which human values may be defined. The idea is to define ecosystem constraints in terms that are measurable with current knowledge and are cautious with respect to the uncertainties inherent in ecosystem manipulation.

Given these constraints, management decisions might proceed within a "safe minimum standard" framework, wherein constraints are relaxed only if judged to be "intolerably costly."[1] Bishop (1978) attempted to motivate the safe minimum standard as a solution to a game theoretic problem whereby maintaining an environmental constraint was

[1] Such an approach should not be confused with an *ad hoc* approach to multiple use management under conditions when the value of some nonmarket goods are unknown. The safe minimum standard (SMS) does not pursue management to "provide the greatest good for the greatest number," as required under the Multiple Use–Sustained Yield Act of 1960. Rather, SMS focuses on tolerance of a constraint.

viewed as the loss-minimizing strategy in the face of uncertainty and irreversibility. Unfortunately, the game theoretic foundation has been found unsatisfactory (Ready and Bishop 1991), but the safe minimum standard approach still offers an intuitive appeal given concerns (Arrow et al. 1995; Holling and Meffe 1996; Stanley 1995) that human decisions without regard to ecosystem health may generate a sudden social-ecological collapse, rather than marginal decreases in quality. However, Randall and Farmer (1995) recently considered the logic (or illogic) of a choice to relax a safe minimum standard constraint; they present one ethical view wherein the constraint is a necessary condition for the survival of human society and wherein a determination that such a constraint is intolerably costly is a revelation that society cannot survive subject to the constraint.

The Randall-Farmer analysis potentially renders the safe minimum standard concept unsuitable for application at the relatively small (nonglobal) scale of individual ecosystems or individual species. However, upon acknowledging persistent gaps in ecological knowledge and the absence of sufficient and uncontroversial valuation research, I believe the idea that decisions in the face of uncertainty may generate truly large (catastrophic) welfare losses, through unanticipated ecosystem collapse, remains intuitively reasonable. This uncertainty provides an appealing motivation upon which to establish ecosystem health and resilience as a goal-constraint of resource management and use. In the face of ecological and economic uncertainty, setting constraints for ecosystem or landscape attributes may well be a rational or reasonable action (Franklin 1989; Gillis 1990; Grumbine 1994; Noss and Cooperrider 1994).

We may need to view the safe minimum standard approach in a hierarchical sense, such that constraints operational at the individual ecosystem level are viewed as disaggregated components of a global-oriented safe minimum standard policy. That policy would be to maintain, to enhance, and to restore ecosystems' health and resilience as the top priority of resource management and environmental use (Noss and Cooperrider 1994, p. 88). The global-oriented (perhaps national or continental) policy would acknowledge Randall and Farmer's (1995) concerns, while the ecosystem level constraints would simply operationalize the safe minimum standard for global ecological health and resilience.

This approach opens a number of avenues for applied economic research. First, as with previous critiques of a safe minimum standard approach (Bishop 1978, 1979; Smith and Krutilla 1979; Randall and Farmer 1995), an open question remains concerning how to define "intolerably high cost" for a constraint. Even if we accept Randall and Farmer's analysis at the global level, there remains the small-scale, operational level of defining "intolerable costs" for specific constraints applied to specific attributes for specific ecosystems.[2] The question becomes "How much of a constraint is enough to be 'safe' *as well as* 'tolerable'?"

Conservation biologists may shed some light on the safety questions, although it may require a professional conjecture based on incomplete ecological knowledge (Grumbine 1994; Kangas and Kuusipalo 1993; Noss and Cooperrider 1994). Economists, however, clearly offer tools to elucidate what are the tolerable implications of an ecological (safety) constraint. Economic contributions may address the cost of a particular ecological constraint, or "level of safety," but, with the aid of ecologists, economists may also elucidate the cost-safety combinations that may be available, thereby contributing to both aspects of the question. These types of studies have already been initiated in forestry applications (Holland et al. 1994; Niese and Strong 1992) as well as broader environmental protection applications (Fisher, Hanemann, and Keeler 1991).

In this spirit, economists may contribute several levels of research. First, economists may trace the cost-minimizing means of achieving a particular environmental or ecological goal. For example, Parks and Kramer (1995) estimate the cost of Congressionally mandated conservation reserve targets, taking account of differing qualities of land in relation to the commercial opportunity cost of preserving that land. Cost effectiveness is an important piece of information, and often it is the best information that can be provided in the face of uncertainty concerning welfare value. However, analyzing cost effectiveness cannot address, for

[2] Obviously, I fail to resolve the issue of whether Randall and Farmer's (1995) critique applies at the smaller scale. If it does, then the operational constraint might be viewed as a minimum standard above which a local or regional economy and society remain viable, so intolerable costs would occur if the local economy could not survive while subject to the constraint, but then a violation of the constraint would lead to an (eventual) collapse of the local society. However, at this scale, the local society may have opportunities to turn to other ecosystems for support. In the spirit of the original Bishop (1978) analysis, while acknowledging the Ready-Bishop correction (1991), at this writing I (like Randall and Farmer 1995) cannot avoid the intuitive appeal that a safe minimum constraint may well operationalize conservation biology's advocacy of ecosystem management. In this context, intolerable cost for a specific ecosystem and its attributes may be judged to occur when the potential losses from maintaining the constraint appear to exceed the net losses from violating the constraint and seeking ecological goods and services from a substitute source. In this case, I implicitly assume the Randall-Farmer critique applies at the larger scale only.

example, the differential effects of the land quality on the benefits of maintaining that land as part of a naturally functioning ecosystem, especially if qualities for developed uses positively correlate with the qualities for ecological services (Swallow 1994, 1996).

Despite the absence of the benefit side, a model to minimize the costs of meeting an ecological constraint can provide important insights into how ecological linkages among components of an ecosystem and interactions among management actions may create scale economies or identify reasons for rapidly increasing costs (Montgomery, Brown, and Adams 1994; Paulsen and Wernstedt 1995). Where costs increase steeply, costs are more likely to exceed benefits as managers tighten the constraint. Also, opportunities to reduce costs can be identified within the framework of a multiproduct firm that provides both a commercial product and the recovery of environmental quality (hereby reducing the opportunity cost of constraints [Roan and Martin 1996]).

Finally, economists may successfully integrate ecological realities within a cost-effectiveness analysis, despite difficulties in bringing such realities into estimation of ecological benefits. Thus, Montgomery, Brown, and Adams (1994) developed an empirical model to evaluate the marginal cost of increasing the probability that the northern spotted owl (*Strix occidentalis caurina*) would exist for 150 years, even though valuation researchers apparently needed to treat the owl's survival as an (unrealistic) all-or-nothing proposition (Rubin, Helfand, and Loomis 1991).

A constrained optimization approach is well suited to the view of ecosystem management as placing human desires secondary to ecological health by setting constraints on management actions that provide ecological goods and services of human interest. Obviously, constrained optimization (especially cost minimization) cannot permit an explicit balancing of ecological protection costs against benefits, but this may not be desirable within the reality of empirical uncertainty for both ecologists and economists (Iverson and Alston 1993) and the demands of decision-makers and conservation advocates on economists (Bromley 1989, 1990; Hahn 1989).

Clearly further work, especially quantitative empirical research, is needed to assess the benefits of ecological conditions in a holistic manner (Bergstrom and Loomis 1995). In some cases, empirical benefit estimates would allow a complete benefit cost analysis. However, such work will remain conditional on an assumption that analysts are talented enough—indeed, omniscient enough—to identify precisely all the ecological conditions that management actions might create and all the means by which ecological conditions affect human welfare. In many cases, such self-confidence is pathological (Holling and Meffe 1996; Noss and Cooperrider 1994; Stanley 1995). In those cases, economists may need to revise the valuation question.

Rather than attempting to actually estimate value, perhaps the question should address the issue of whether the chosen ecological constraints may be achieved at "tolerable costs." For example, can economists find that it is reasonable for society to accept $13 billion in costs to manage the northwestern ecosystem in a manner that raises the probability of Northern Spotted Owl survival from 91% to 95%, or do we find that society only believes that $12 billion is a reasonable cost to manage the ecosystem in a manner that raises the owl's survival probability from 82% to 91%?[3] Such an approach may appear identical with the usual valuation question, but I intend to suggest a subtle but important distinction. A focus on the owl may serve simply to operationalize the objective of maintaining a healthy and productive ecosystem. The Northern Spotted Owl may be viewed as an "umbrella" species, the preservation of which necessarily creates a means to conserve a host of ecosystem attributes (Noss and Cooperrider 1994, p. 8). These myriad ecosystem attributes may be only partially described, including the owl's survival probability and the allocation of lands between owl habitat and timber production. The social valuation question may rely on an imprecise appeal that management is attempting to maintain ecosystem health and that the owl's survival is one indicator of management success.

In short, my suggestion is to recast the valuation question in a manner that more explicitly considers the safe minimum standard's requirement to define tolerable costs. We do not know, and we may never know, all the ecosystem contributions to human welfare, so the question becomes one of tolerating ecosystem constraints that are cautious in the face of pure uncertainty and, possibly, unresolved issues concerning an appropriate value system (Bengston 1994; Bergstrom and Loomis 1995; Randall 1994). I have not found such an approach in the literature, but perhaps Ruitenbeek's rainforest study (1992) arguably represents a step in this direction; that study compares the opportunity

[3] The numbers chosen here are from Montgomery, Brown, and Adams (1994). Those authors also discuss the importance of equity or distributional issues in terms of the incidence of costs and benefits from maintaining the ecological constraint.

costs of preservation with the magnitude of international transfer-payments for preservation. Economists will need to develop innovative approaches, such as ambivalence theory (Opaluch and Segerson 1989) or neoclassical approaches, as a basis to evaluate tolerable costs.

Producing "Ecosystem Condition" and the Relevance of Economics

If one draws on a text, such as Noss and Cooperrider (1994), to understand the conservation biological recommendations for ecosystem management, one finds a mixture of ecological science and conservation-oriented value judgment. Noss and Cooperrider repeatedly emphasize that the conservation of biodiversity and the restoration and maintenance of healthy productive ecosystems are simply the ethically correct and dominant (lexicographically) objectives of human interactions with ecosystems. They do recognize a role for addressing human preferences or economic values, but primarily in recognition that public relations, public education, and political institutions may provide means to facilitate the ethically unassailable goal. That the goal of widespread ecosystem health and resilience may face competition for the moral high-ground is not considered (Randall 1994). At times, conservation biologists offer seemingly innocuous statements that economists may find unreasonable or extreme.

For example, Noss and Cooperrider (1994, p. 90) suggest that no region should be designated a sacrifice zone,[4] yet Vincent and Binkley (1993) (cf. Helfand and Rubin 1994; Swallow and Wear 1993) identify conditions under which noncommercial ecosystem attributes within a landscape may be enhanced by designating some zones for intensive development and others for intensive protection. Indeed, combining these conditions with political reality motivates much of the approach to addressing the Northern Spotted Owl issue (Montgomery, Brown, and Adams 1994). Noss and Cooperrider go even further as they introduce a strategy for development of an ecosystem reserve network as a central recommendation of conservation biology:

> The strategy rejects resource tradeoffs and insists that we can have the best of all possible worlds if we put our minds to it and are willing to reduce our resource consumption and intensity of land use for the sake of the land. (1994, p. 146)

Economists, of course, immediately recognize that a willingness to reduce consumption is a resource tradeoff made in return for whatever goods we would receive from a healthier ecosystem, or for whatever good feelings we have about sacrifice "for the sake of the land." With due respect, one is left to wonder how conservation biology and ecosystem management actually can "reject resource tradeoffs."

A partial answer arises in the determination of ecological constraints, as discussed above. However, economists may be of greater service to ecosystem management and policy by helping to identify where resource tradeoffs are implicit—where even biologists must resort to value judgment, as some conservation biology literature has begun to do (Hagan 1995; Kangas and Kuusipalo 1993; Lélé and Norgaard 1996)—and when attention to resource tradeoffs and individual preferences can enhance the goals of ecosystem management. To accomplish this, economists need a basic understanding of alternative strategies to produce ecosystem attributes.

Managing for Diverse and Resilient Ecosystems

Conservation biologists (Grumbine 1994; Hunter 1990; Noss 1990; Noss and Cooperrider 1994) offer ecosystem management as the most promising approach to maintain global biodiversity. Its goals, according to Grumbine, are (1) to maintain viable populations of all species in situ; (2) to represent all native ecosystems; (3) to maintain evolutionary and ecological processes; (4) to plan for evolutionarily relevant time; and (5) to accommodate human use within these constraints. The approach generally attempts to reduce forest (ecosystem) fragmentation so that land units may be aggregated at scales large enough to exhibit natural processes and to protect species with unique adaptations for interior habitats free of influence from edges of abrupt, unnatural habitat change (Franklin 1989; Franklin and Forman 1987; Gillis 1990; Noss and Cooperrider 1994; Turner 1989).

In general, the approach is quite holistic, rather than following an "autecological" or "single-species" approach. In many cases when management plans appear autecological, the focal species will be a "keystone species," the survival of which is believed essential to the survival of many

[4] I use Noss and Cooperrider as an example since their text is so widely respected. Certainly their arguments are not entirely atypical of conservation biological philosophy (Grumbine 1994; Hunter 1990; Stanley 1995). The point here is only to begin identifying areas where economists may contribute both to developing a tighter rationale to promote conservation goals and to identifying areas where conservation biology faces unavoidable tradeoffs.

other ecosystem components, or the focal species will be an "umbrella species," the management of which will automatically protect and enhance habitats for a variety of species and processes at a landscape scale. A focus on a keystone or umbrella species is a practical, but imperfect, approach to simplify safely the complexity of ecological attributes that command attention.

Multiple use modules: building blocks for reserve networks. At the landscape scale, especially in developed temperate countries, consensus recommends a network of ecological reserves managed on the concept of a "multiple use module" (Noss and Cooperrider 1994, pp. 144–61).[5] This approach builds on lands allocated as core reserves in which extractive or consumptive uses are, in most cases, prohibited. Surrounding each core reserve is a graduation of buffer zones in which progressively more intensive human use may be permitted as one moves away from the core reserve. The buffers are designed to protect the interior of the core from "unnatural" ecological processes that may arise from sudden changes in habitat structure. For example, Noss and Cooperrider (1994) cite a number of studies suggesting that forest clearcuts affect microclimatic factors, such as wind, temperature, or moisture regimes, for up to 200 meters into a neighboring, unharvested habitat patch, and that these factors affect ecological processes such as tree mortality rates and windthrow. The multiple use module consists of the core and its buffers, with progressively more intensive, consumption-oriented management for multiple uses toward the outer buffer (figure 1). A reserve network, for example, consists of two or more multiple use modules that are connected either by designated corridors or, if corridors are infeasible, by a surrounding landscape (a surrounding "matrix") in which existing land uses do not present insurmountable barriers to dispersal of individual flora and fauna between core reserves.

The geometry of the multiple use module immediately raises resource tradeoffs for managers. The immediate question is where, geographically, to locate the boundaries between a core reserve and its inner buffer and between the inner and outer buffers. Wear (1992), followed by Gottfried, Wear, and Lee (1996), identified such spatial tradeoffs of ecosystem management as the "economies of configuration." Assuming a circular shape in this example (figure 1),[6] the fundamentals

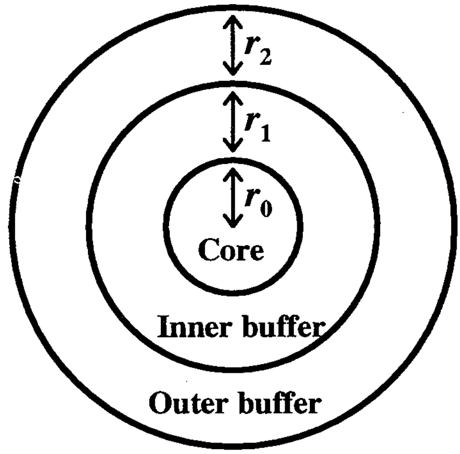

Figure 1. Idealized Multiple Use Module. Module consists of a highly protected core reserve, of radius r_0, surrounded by progressively less protected buffer zones allowing greater multiple use, with respective buffer widths of r_1 and r_2.

of a cost analysis for a multiple use module are a straightforward implication of two-dimensional geometry. The ecological contribution of each portion of the module is, as a first cut, a function of the radius of the appropriate circle, which determines the naturalness of the core's interior and, through the associated acreage, the ability of the module to sustain natural rates of ecological disturbances, such as fire. The radius and acreage would be inputs to the "production function" for constraints on biodiversity or ecological resilience within the module. For a given ecological constraint, however, the opportunity cost depends on the land area (acreage) within each zone, which increases with the square of the radius. In addition, cost depends on the degree of restrictions imposed on consumptive uses, with the core reserve prohibiting nearly all consumptive uses and probably restricting recreation access, while the buffers prohibit progressively fewer uses.

Increasing the size of the core, through increasing its radius, entails the greatest opportunity cost but likely contributes most to achieving the ecological diversity and resilience constraints. Increasing the core's radius has two implications for the cost of achieving the ecological constraints. First, increasing the radius increases the land allocated to the core, with restrictions that impose the

[5] The U.S. and U.N. Man in the Biosphere programs have adopted this strategy (David Wear 1996, personal communication).

[6] Noss and Cooperrider (1994, pp. 138–77) discuss the optimal shapes for units in a reserve network. They prefer a circular shape for greater integrity of the interior habitat, while they also recommend larger cores, with connecting corridors, and relative geographic positions that enhance interactions among all modules directly. See also Hof and Joyce (1992).

highest opportunity cost per acre. Second, increasing the core's radius pushes the outer boundary of a fixed-width buffer out further, so that the acreage allocated to each buffer tends to increase, increasing the use restrictions on additional acres. However, fixed-width buffers are not required for ecological integrity, because a larger core reserve provides a self-buffering capacity for its own interior. The buffers serve both to increase the area within the core that is truly "interior forest" and to contribute to ecological goals, for example, by increasing the habitat area for species that may thrive on disturbances created by multiple uses within the buffer. We expect, therefore, that the width of the buffers may be adjusted to some degree as the core reserve increases. Then the boundaries within the multiple use module would be chosen so that the marginal cost of an improvement in the appropriate ecological goal (as represented, perhaps, by a biologically determined constraint) through a change in the width of one portion of the module (figure 1) would be set equal across all portions of the module.

Noss and Cooperrider (1994) implicitly deny that the multiple use module approach engages in such resource tradeoffs, but economists can wonder—and can demonstrate—that the choice of boundary locations by a conservation biologist at least reflects the biologist's subjective balancing of the contributions of each zone to the ecological constraint and the political-economic feasibility of implementing these boundaries. What may be more in dispute is not whether the multiple use module requires an implicit set of tradeoffs, but whether the values of the conservation biologist or the values of some human constituency (the biologist's private client or the public) "should" be weighed more heavily in determining the parameters of the cost minimization problem. Below, I provide foundations for a preliminary rationale for why the conservation biologist might want to use public preferences as the basis for cost analysis.

From modules to reserve networks. A collection of one or more multiple use modules is inadequate, according to Noss and Cooperrider (1994), for example, to ensure a healthy and diverse ecosystem at regional or global scales. A consensus goal identified by Grumbine (1994) is to adopt an ecological and evolutionary time frame. This goal implies ecosystem management to permit genetic exchange between separate populations of a species and to create means by which species may alter or extend their range as long-term conditions, such as global temperature, change, and species disperse and begin to capture new ecological niches. Moreover, an ecosystem management goal is to preserve a representative sample of all ecosystems, which cannot be accomplished with a single multiple use module of less than continental size. Conservation biologists therefore recommend development of corridors and removal of dispersal barriers (e.g., roads) between multiple use modules, creating a network of ecologically linked core reserves (figure 2).

The reserve concept adds several dimensions to a cost analysis of ecosystem management. First, the cost analysis would include the contribution of the corridor to meeting ecological constraints

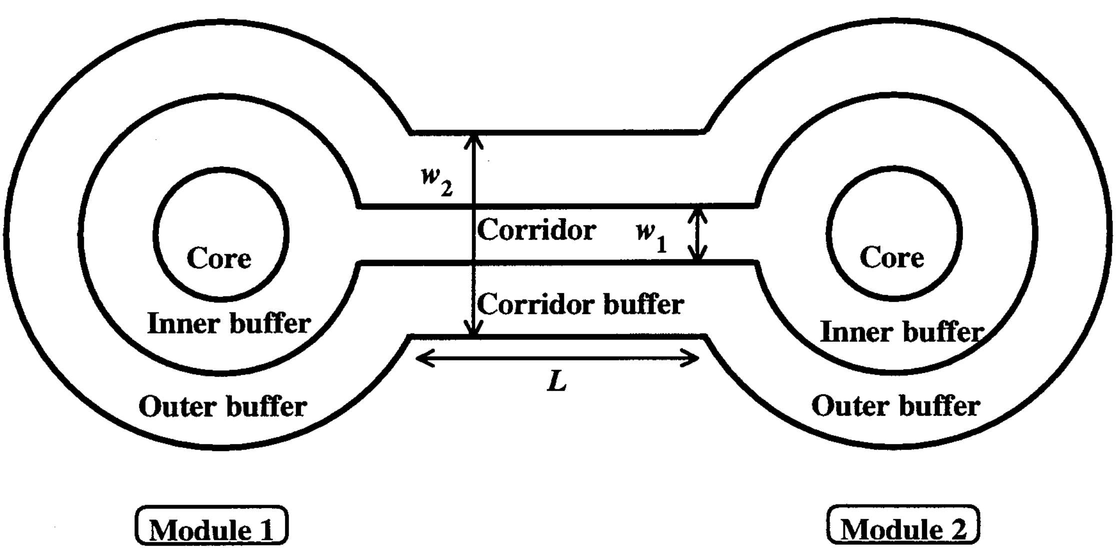

Figure 2. Stylized Reserve Network of Two Multiple Use Modules and Connecting Corridor. Main corridor width is w_1; width between corridor-buffer boundaries is w_2; corridor length is L.

while balancing the marginal costs of increasing ecosystem quality by widening the main corridor boundary and its buffer zone or zones.[7] Second, and more subtle, the consideration of one or more additional modules raises the issue of landscape scale in the calculation of the ecosystem constraints.

The issues associated with scale arise from some paradoxes or ironies of conservation biology. For example, Hunter (1990) and Noss and Cooperrider (1994) immediately acknowledge that, to maximize biodiversity at the local scale, one would include a much higher degree of habitat fragmentation and perhaps even maximize the length of "edge" between habitats of different types, such as between forest patches of different ages (Franklin and Foreman 1987; Hof and Joyce 1992). A fragmented landscape pattern encourages opportunistic species or species that are adapted to or require several habitat types for support. However, given the substantial fragmentation of the human-developed landscape, biologists find that most "fragmentation-adapted" species will be common and well suited to survival in a human-impacted environment. Thus, regional diversity might be limited by failure to look at species composition between habitats and across regions (Noss and Cooperrider 1994, p. 10). Reserves representing different habitat types, which support different species assemblages, will create greater diversity at a regional scale or global scale, particularly since core reserves would support species dependent on forest interiors, while the inner and outer buffers provide for species adapted to progressively more heterogeneous (fragmented) habitats.

From an economic perspective, the addition of multiple use modules creates a number of substitution possibilities within a cost minimization framework. For a fixed ecological quality constraint, increases in the diversity or ecological resilience of one module may relax the need for contributions from another module. These substitution possibilities may allow economists to consider different cost-minimizing configurations of boundaries between the components of each module. Furthermore, changes in the width, length, and character or effectiveness of corridors between modules may allow ecosystem interactions that enhance the ecosystem condition of both modules, again allowing reduction in the cost of particular ecological constraints.

Cost Minimization Alone Is Not Enough

In some cases, managers may consider the targeted biodiversity or ecosystem resilience constraint to be invariant to the number of modules in a reserve network. In that case, cost minimization might allow a reduction in the size of individual multiple use modules—the individual reserves—as a reserve network grows to represent more ecosystem types. However, any conservation biologist who remains true to the mission-oriented science would likely advocate an increase in the level of biodiversity or resilience targeted for a larger network. Of course, any constraint may be chosen on the basis of noneconomic criteria. However, at some point, economists can contribute to ecosystem management through elucidating the role of public preferences in developing public support for ecosystem management and how that support may depend upon the chosen constraint. This task has at least two parts: identifying just what ecosystem management contributes to human welfare—other than the traditional multiple commercial, noncommercial, and aesthetic uses—and identifying whether and how ecosystem managers might influence the composition of those contributions to increase the public support for conservation biological goals.

Social science literature on what the public may gain from ecosystem management has begun to appear (Bingham et al. 1995; Brunson and Shelby 1992; Gale and Cordray 1991). Already it seems clear that simply valuing biodiversity without regard to species composition—counting insect species the same as bird species, for example—is not consistent with a qualitative understanding of public preferences (Hunter 1990; Noss and Cooperrider 1994), nor is it consistent with how public agencies have revealed their preferences via expenditures on endangered species (Metrick and Weitzman 1996). However, conservation biologists propose to enroll between 25% and 75% of all land in most regions in a reserve network, with some estimates reaching above 99% (Noss and Cooperrider 1994, pp. 167–72), as necessary to meet conservation goals and allow for an acceptable quality of life for humans and other species.

With such bold proposals, and given the undeniable power of society to alter ecosystems, it seems prudent to consider the extent to which public support exists to make such a goal into reality. Might conservation objectives gain from implementing resource tradeoffs that enhance the will-

[7] Noss and Cooperrider (1994) represent the main corridor as, ideally, a strip of land with protection and ecological integrity suitable to the core reserves and surrounded by a gradation of multiple use buffers. I have relaxed this ideal somewhat by assuming that, especially in temperate and developed North America, the core reserves would not be connected by land with the same ecological quality. Of course, managers might impose strong constraints on activities permitted in the main corridor.

ingness of the public to support creation of a reserve system? Might the relative weight that ecosystem managers give to biodiversity and ecosystem health be judged, validly, by a broader segment of the public than the card-carrying conservation biologists, who, after all, are responsible for enduring only part of the opportunity costs of setting "tolerable minimum standards"? Is is not true, at least, that the preferences of the public constitute relevant information for the decision process, particularly for decisions that affect people who voluntarily contribute to conservation or acquiesce to conservation regulations?[8]

The economic intuition here is fairly straightforward. For example, suppose society adopts a constraint that all ecosystem types should be represented in area sufficient to prevent their endangerment. Recalling that maintenance of biodiversity may be easier with larger reserves and that different reserves may have different species assemblages (Noss and Cooperrider 1994, pp. 10, 208), biologists might appreciate information on public preferences for each ecosystem as they determine how to balance additional investments in each.

For a simple, almost trivial, example, consider that, in a particular region, two ecosystem types are of concern. Suppose that the cost of adding an acre to the core reserve for each ecosystem is the same and that ecological science provides no means to judge unambiguously concerning which reserve should have more acreage. If an individual has a relatively stronger preference for ecosystem type 2, then their individual willingness to pay curves might be represented by the downward sloping "demand" curves in figure 3a. Suppose ecosystem managers impose an egalitarian approach, placing Q acres of each ecosystem in the reserve network. Then the total willingness to pay of this individual is given by the area $0ACQ$ + $0ABQ$ (figure 3a). In contrast, consider the case where managers take an economist's advice and add land to each reserve so that the individual's marginal willingness to pay for an additional acre is equal with respect to each reserve. Figure 3b represents this situation, where the managers preserve the same number of acres in total but divide it in unequal lots, Q_1 and Q_2, between the respective ecosystems 1 and 2 (so $Q_1 + Q_2 = 2 \cdot Q$; figure 3). With the economist's approach, it is easily shown that the total willingness to pay area, $0AEQ_1 + 0ADQ_2$, exceeds the original total.[9]

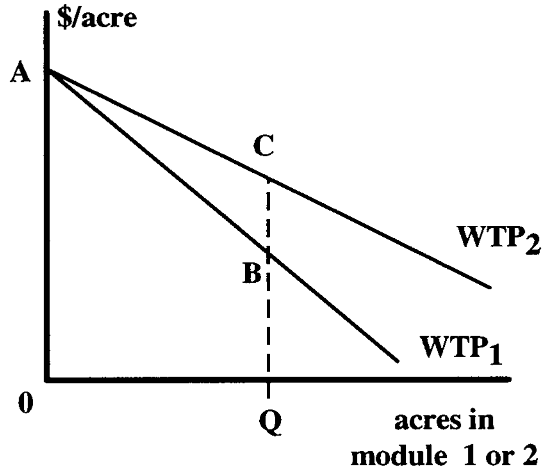

Figure 3a. Egalitarian Approach

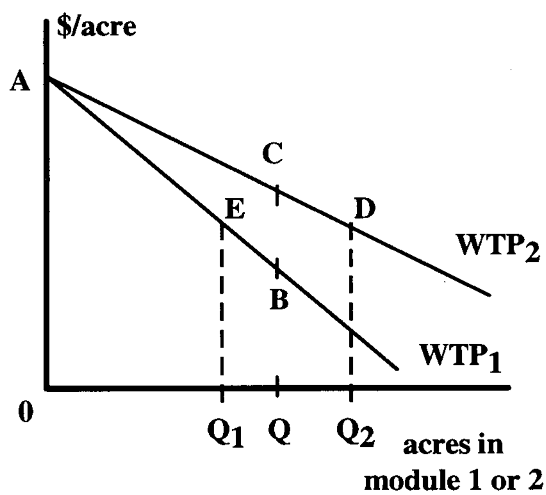

Figure 3b. Economic Approach

Figure 3. Comparison of Willingness to Pay (WTP) for Additions of Land within Two Multiple Use Modules Representing Different Ecosystem Types. Figure 3a. Under an egalitarian approach with equal acreage in each module, total WTP is given by area $0ABQ + 0ACQ$, with total acreage preserved of $2 \cdot Q$. Figure 3b. Under an economic approach, total WTP increases to $0AEQ_1 + 0AEQ_2$, with total acreage preserved of $Q_1 + Q_2 = 2 \cdot Q$.

[8] Economists will find Sagoff's discussion (1994) quite challenging on this point.

[9] This result holds because the individual's willingness to pay for each of the last few acres in ecosystem 1 under the egalitarian approach (Q–Q_1) is lower than their willingness to pay for the units of the more highly preferred ecosystem 2 that are gained under the economic approach (Q_2–Q).

This result should interest ecosystem managers in two ways. First, under the economic approach, the ecosystem manager has a greater potential for fundraising. Second, under the economic approach, the manager is more likely to gain the vote of an individual for a program to set aside a given number of acres ($2 \cdot Q$). Either of these reasons implies that the economic approach may foster greater public support, thereby potentially allowing greater additions to the reserve system.

But a question remains: Why would an individual value the two ecosystems differently? The answer depends on what the ecosystems and their managers offer. For example, ecosystem 2 might be relatively more scenic, or better able to support modest amounts of public access (user days) for passive recreation. Depending on the other attributes of the region, especially the matrix of land uses outside the reserve system, individuals may simply feel their quality of life gains more from ecosystem 2, which might represent species assemblages that are locally uncommon but globally common.

Economic research to quantify public support for ecosystem reserves needs to instruct managers on the interactions between elements of the reserve and public preferences. For example, regional differences in biodiversity and the composition of local species assemblages may generate demand-side substitution effects. In an intertemporal setting at a local scale, these ecological and preference interactions produce wealth effects also (Swallow and Wear 1993). In addition, heterogeneity between segments of the public may generate support for a mixture of programs tailored to that heterogeneity. For example, geographic differences in local ecological quality (wealth) may enhance or diminish the local public's support for programs pertaining to certain ecosystem qualities. Also, differences in preferential emphasis, such as one group desiring access to healthy ecosystems while a second group prefers managing ecosystems for minimal human influence, may allow managers to leverage support from both groups by managing reserve elements with different degrees of public access to the core. Such effects generate a complex analytical problem for a holistic approach to continental or global ecosystem management, but economists should be able to shed light on how conservation biologists could leverage public preferences to achieve their goals or to make ecological constraints most tolerable.

Recent ecological research produced an ironic result that also deserves notice. Tilman's (1996) freshly published "classic" (Moffat 1996) shows that diverse ecosystems may well be hazardous to the preservation of individual species. The ecological intuition is rather direct, as follows. Ecological stresses open opportunities for species in an ecosystem to replace an existing, more dominant species, and diverse ecosystems have more species "waiting" for natural or human-induced stress to create conditions that favor its particular adaptations. These observations mean that post-stress competition between species may permanently depress the population of a particular species, but that the overall biomass of the more diverse ecosystem may be more stable. A more diverse ecosystem has a more stable biomass because diversity increases the odds that a species is available to fill any voids created by, for example, a drought that devastates a drought-intolerant species. The result means that biodiversity aids ecosystem health and stability but may further threaten endangered species. For economists, this ecological research raises the question of appropriate relative investments in holistic, ecosystem management approaches versus autecological, single-species programs created by endangered species legislation.

Of course, as economists try to elucidate the link between public preferences and public support for conservation, we will also need to clearly identify our own field's ironies. One irony, in particular, is that a holistic approach to ecosystem valuation (Bergstrom and Loomis 1995) may actually lead to less total investment in conservation, as compared with a series of less-holistic benefit-cost analyses (Hoehn 1991; Hoehn and Randall 1989). Holistic valuation will account for substitution among different sources of biodiversity or ecosystem resilience, and thereby prevent unintentional overinvestment (from a Pareto efficiency viewpoint) in environmental programs. Obviously, some groups may prefer this " 'Pareto' overinvestment," which economists would honestly reveal.

Incentives and Marketing for Ecosystem Management

Most discussions of ecosystem management have focused on public lands, but most public land boundaries were chosen for political or administrative convenience rather than being based on reasonable ecological boundaries. For example, only 15% or less of the Greater Yellowstone Ecosystem (14–19 million acres) lies within the Yellowstone National Park (2.2 million acres), and perhaps only two-thirds of the ecosystem is contained within public lands of any kind, including those with intensive human uses (see Noss and Cooperrider 1994, pp. 133–38). Moreover, about 40%

of major terrestrial ecosystems in the United States are *not* represented in wilderness areas, and no wilderness areas outside Alaska are large enough to support long-term populations of large carnivores. Obviously, if an objective of ecosystem management is the preservation of representatives of all ecosystems, cooperation among landowners across the public and private sectors is required.

Therefore, the issue of public preferences for ecosystem attributes also relates directly to creating incentives for private, individual actions that enhance ecosystem health and for raising funds to support conservation. First steps may concern marketing, while the complexities of an ecosystem divided among many landowners provide unique challenges.

On the marketing side, conservation biologists have already exploited the concept of a "flagship" species, whereby conservation groups promote a broad agenda, such as wilderness preservation, by focusing public attention on a particularly attractive, aesthetically pleasing species like caribou (*Rangifer* spp.) or the Northern Spotted Owl (Noss and Cooperrider 1994, p. 8).[10] Marketing to gain public financial support or favorable voter behavior instead may focus on "umbrella" or "keystone" species, by identifying the associated species assemblages and ecosystem attributes that may be preserved along with the umbrella or keystone species. This approach is more consistent with ecological priorities. Economists may help identify the public's willingness to support programs associated with ecologically consistent marketing and identify the conservation advantages of the trust that such an approach develops in the public (cf. Swallow et al. 1995).

There is a rapidly growing literature on creating mechanisms by which private individuals and firms may gain or generate incentives to manage ecosystem resources for biological diversity. Several studies have contributed to developing a rational framework for evaluating the composition of species assemblages, rather than simply giving all species and taxonomic ranks equal weight in a "diversity index" (Polasky and Solow 1995; Solow, Polasky, and Broadus 1993; Weitzman 1992, 1993). Unfortunately for ecosystem preservation, there is some indication that the commercial value of biodiversity, at the margin, may be small (Simpson, Sedjo, and Reid 1996; Simpson and Sedjo 1996). However, the nonmarket value of biodiversity remains a largely unexamined area, at least in a holistic sense (rather than with a focus on single species).

Moreover, the literature provides some evidence that the public values ecosystems not simply for biodiversity (Bengston 1994); rather, the public may be calling for a decrease in the human impact and encroachment on healthy, well-functioning ecosystems. Economists' traditional focus on quantities measured in numbers, like numbers of species or acres of land preserved, may actually misrepresent—or only partially represent—how ecosystems contribute to the public's quality of life. Economic and social science research may reveal that the public's interest focuses, perhaps in large part, on the degree of impact that human society has on, for example, a continental ecosystem. Appropriate units of measure may be the percentage of ecosystem types that remain represented in the long-run, or the percentage of species that may survive, or the percentage of "originally" forested land that has been permanently cleared. The quantities of resources, such as land area, that ecosystem management commits to preservation or restricted human use will clearly determine the opportunity cost of producing the desired ecosystem condition, but the "ecosystem product" that is provided may require measurement in less conventional terms.

The issue then becomes one of identifying the public value of desirable land management actions, from an ecosystem management viewpoint, and then creating mechanisms for bringing these values into the incentive structure of individual landowners. Burton (1996) recently proposed a mechanism by which "environmentalists" and "industry" can be brought together to truthfully reveal their relative preferences for alternative land uses, leading directly to incentives to improve the efficiency of land-use. While his framework anticipates that the "environmentalists" may reject the traditional approach of translating aesthetic values to monetary terms, Burton's promising approach awaits extension to the spatial and temporal context within which substitution and wealth effects may arise from geographic and temporal differences in ecosystem attributes or biodiversity.

In the forestry literature, several authors have initiated discussion on whether regulation of private land or a system of market incentives would involve the least transaction costs for the greatest gain from landowner cooperation. The tentative conclusion, without empirical support, is that regulations may be costly to implement and enforce, while incentives—even if imperfect—may leave landowners with a greater degree of trust in government's protection of their rights to make land

[10] The "flagship" species may also allow conservation groups to enlist the Endangered Species Act as a strong legal framework to pursue broad conservation goals.

use choices (Gottfried, Wear, and Lee 1996; Sample 1994; Wear 1992). For example, landowners may fear that regulation will increase the likelihood that government will identify the individual's land as "critical habitat which should never be harvested," causing the landowner either to face substantial bureaucratic inconvenience or to forgo desired management options. This fear may create strong political opposition to a regulatory approach, opposition that may not be so severe for an incentives approach. However, some incentives approaches may also generate political-economic opposition. For example, implementation of national or international "eco-labels," which certify to consumers that wood products derive from forest land under ecologically sensitive management, raises concerns among landowners that "environmentalists" may capture certification organizations and impose unreasonable (or intolerable) standards that ultimately disadvantage landowners (Linddal 1996; Sullivan 1996; personal observation).

Importantly, this literature has also raised the concern that land use restrictions in one region may generate demands for commercial products from another region, thereby exporting human-caused ecosystem stresses from the first region to the second (Lippke and Oliver 1993). Murray and Wear (1996), for example, show that owl management may have reduced harvest from the Pacific Northwest by about 4.25 billion board-feet between 1988 and 1992. Sedjo (1996b) provides evidence that the management plan for the Northern Spotted Owl did indeed export demand for commercial extraction to other portions of the global ecosystem.

Landowners within the multiple use module. Policy and economic research is nearly absent concerning the development of regulations or incentives designed specifically to gain landowner cooperation in ecosystem management. One reason is the historic focus on multiple use management that targeted lands under public ownership (Bowes and Krutilla 1989; Wear, Turner, and Flamm 1996). Many of the multiple use approaches do not fully recognize spatial and intertemporal linkages across management units within a forest ecosystem (Hof and Joyce 1992; Swallow and Wear 1993). More recent concern for the whole ecosystem, regardless of management boundaries, generates new attention to the configuration of public lands and their linkage to private land (Albers 1996; Swallow and Wear 1993; Swallow, Talukdar, and Wear in press; Wear 1992). Wear (1992) and Gottfried, Wear, and Lee (1996) suggest the possibility that specializing public lands toward the provision of "ecological condition" might make unnecessary costs associated with government intervention via either regulatory or incentive strategies; public lands could provide for ecological health and resilience while private lands could provide market goods, and the overall costs of achieving the ecosystem objective might be lower than with an approach that attempts to coordinate management of many public and private land units. However, because "gap analysis" (Noss and Cooperrider 1994, pp. 133–38) shows that 40% of U.S. ecosystem types remain unrepresented in wilderness reserves, conservation biologists will likely seek cooperation from private landowners and nonwilderness agencies.

Currently, however, the literature provides no empirical estimates of the costs of government intervention, for either regulatory or incentives approaches, for comparison with the opportunity costs of achieving any particular constraint on ecosystem condition.[11] Such a comparison awaits development of a framework for exploring means to gain landowner cooperation within, for example, a multiple use module.

The example illustrated in figure 4 provides some indication of the complexity of economic issues that the multi-landowner context raises. In this example, I assume that the multiple use module is centered on a core reserve that a public ecosystem manager (conveniently) controls, but that the inner and outer buffers may be divided among several private owners (or commodity-oriented public agencies). I also assume, for convenience, that landowner boundaries do not cross boundaries between the core reserve and its inner buffer or between the two buffers. This illustration permits a discussion of interactions among land parcels, based on both the geographic and the temporal linkages among parcels. As previously discussed, conservation biologists recommend that lands within the inner buffer (parcels 1–4) be managed for less-intensive multiple uses, because of their location next to the core reserve. However, the ecosystem manager likely must offer incentives if these landowners are asked to voluntarily reduce their commercial timber harvests by 50 to 100%. Familiar approaches, such as tax credits or conservation-reserve programs, will require evaluation (Lippke and Oliver 1993; Sample 1994).

However, economists could propose newer, innovative approaches, such as public-private coop-

[11] As already noted above, the nonmarket benefits of a given ecosystem condition remain unknown, so I have made this statement only as a comparison of costs.

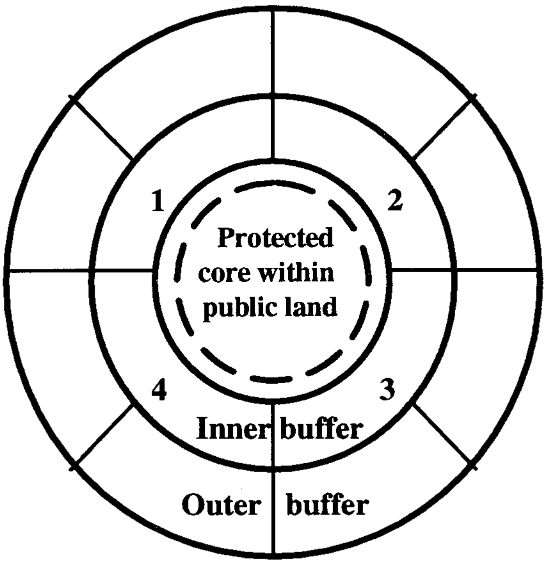

Figure 4. Multiple Use Module with a Publicly Owned Center and Multi-ownership of Inner and Outer Buffers. Public managers bargain for cooperation with other landowners and may set the boundary of the core reserve so that the margin of public land becomes part of the inner buffer.

eratives, perhaps modeled on the idea of a "conservation district." For example, if the core reserve is reasonably large, then public managers might gain some ecological advantage by allowing the outermost portion of the publicly owned center to be managed as a part of the inner buffer (dashed boundary in figure 4). Such a decision raises the tradeoffs implicit in choosing the boundary between the core and the inner buffer. However, an innovative definition of the core's boundary might enable managers to grant some extraction rights to landowners within the main inner buffer in exchange for the landowners' agreement to manage their parcels in a manner consistent with the ecosystem management plan. Such an arrangement would allow the ultimate core reserve to exist within a more effective inner buffer, as compared with the situation where landowners within the buffer refuse to cooperate. Moreover, the approach may provide local managers, who may hold location-specific expertise, to achieve more specialized control without the political-economic challenges associated with explicit tax or subsidy approaches.

Furthermore, in some case, public land may extend, for example, to a portion of the outer buffer or to the land-use matrix surrounding the module. In these locations, ecosystem management would allow more intensive uses, like commercial timber harvests. In such a case, managers may have even more flexibility to negotiate cooperative agreements with private landowners, since a higher extraction rate may be permissible to swap for cooperation.

The economics of this situation remains unaddressed. Albers (1996), Swallow and Wear (1993), and Swallow, Talukdar, and Wear (in press) have provided spatially explicit, intertemporal models that may offer a foundation for future work. But none of those studies is tailored to the framework of a reserve network of multiple use modules; the empirical portions of those studies might best be viewed as applicable to a group of neighboring parcels within a module. However, these authors make clear that both spatial and intertemporal conditions would affect ecosystem management choices for any particular parcel. For example, Swallow and Wear (1993) show that a manager of a single parcel would select different intensities of harvest at different times, depending on the condition of the forest on a neighboring parcel.

Economists using game theory may contribute to developing policies or approaches to establish landowner cooperation within ecosystem management.[12] Such research would draw on the economics of nonindustrial private forestry (e.g., Boyd 1984; Hyberg and Holthausen 1989; Koskela 1989; Kuuluvainen, Karppinen, and Ovaskainen 1996; Kuuluvainen and Salo 1991; Max and Lehman 1988) in an effort to identify approaches to leverage the value that these landowners may place on noncommercial services from their forest land. Newman and Wear (1993) show that nonindustrial private forest owners place a value on standing timber stock that exceeds the value revealed by industrial forest owners, indicating a potential opportunity for bargaining by ecosystem managers. For example, such a differential raises an opportunity for managers to gain control of "harvest rights" to some private parcels for an opportunity cost that falls below the market value of standing timber. However, Provencher and Swallow (1995) indicate that if landowners have access to ecosystem resources on neighboring parcels, they may be less inclined to forego income from commercial harvests in order to enhance noncommercial values from their land. These studies all raise complicated challenges for the application of game theory to ecosystem management in general, and reserve networks in particular.

[12] Piyali Talukdar is nearing completion of a dissertation based on a game theoretic approach.

Summary

This paper provides an overview of ecosystem management and economic issues motivated by traditional multiple use management and by conservation biologists. While ecosystem management may be viewed appropriately as an extension of multiple use management for many managers, the dominant theme in the literature of conservation biology seems consistent with setting constraints on ecosystem attributes and allowing human activity within those constraints. If ecosystem management is viewed as an extension of multiple use, then economists may focus attention on providing a complete valuation of the mix of outputs included in the extended objective function. Such an approach is convenient for an economist's predisposition to identify efficient management strategies, but it overlooks the complexity of first identifying and then valuing all the ecosystem attributes that may be relevant.

Facing complexity and uncertainty of ecological knowledge, managers operationalize goals for ecosystem attributes as constraints on the production of goods and services for humans. This view leads toward the economics of a safe minimum standard, including the possibility that economists might revise their emphasis on benefits and begin to emphasize how tight a constraint society considers "tolerable." Of course, Randall and Farmer (1995) argue that a safe minimum standard applies only for global- or continental-scale policies. In that case ecosystem-level constraints represent disaggregated components of the safe minimum standard. As components of a larger constraint policy, substitution possibilities exist among the ecosystem-level constraints.

The paper also reviews the insistence by conservation biologists that valid ecosystem management necessarily rejects resource tradeoffs. In the context of establishing a network of ecological reserves, designed on the concept of multiple use modules, the review shows that resource tradeoffs are unavoidable. Economists may contribute to ecosystem management by identifying where tradeoffs occur and by characterizing the tradeoffs implicit in the management choices. Cost minimization identifies tradeoffs implicit in establishing reserve cores and buffer zones, and economists may base cost minimization on ecologically sound models even when ecological uncertainty makes benefit analysis controversial. Also, the relationship between cost and constraints may elucidate a "tolerable" constraint. In addition, when analysis of public preferences is feasible, economists may cast results within a framework that suggests how ecosystem managers may manipulate the design of a reserve system in order to enhance the public's financial or political support for a particular ecosystem management program or for more aggressive goals.

Economists can also analyze geographic or spatial issues in ecosystem management. For example, the analysis suggests that the opportunity cost of allocating an additional acre to a core reserve derives not only from the opportunities forgone because of restrictions on land use in the core, but also from the concomitant allocation of land to buffer zones, which imposes opportunity costs on owners of those acres. Furthermore, development of a reserve network will raise possible substitution and wealth effects associated with the geographic differences in biodiversity supported by each multiple use module. These effects raise the potential for managers to meet a given standard or constraint while reducing costs or restrictions on some elements of the reserve network. Furthermore, the geographic differences in biodiversity endowments may interact with public preferences to alter the willingness of different human communities to support ecosystem management objectives, and economic research could identify these interactions.

An open area for future research remains the development of institutions, regulations, or incentives to cause individual and independent landowners to cooperate with ecosystem managers. Existing literature debates whether regulatory or incentives approaches would be less costly means for government intervention to inject scarce ecosystem attributes within individual decisions, but applied evaluation is nonexistent. A consensus exists that new institutional mechanisms should leverage the advantages of local managers, who can develop detailed knowledge of local ecosystems and who can respond more rapidly to changing circumstances.

Economists may identify new roles for public land in some institutions that encourage landowner cooperatives—or ecosystem conservation districts—to form multiple use modules. Our public land system leaves substantial gaps relative to the conservation biologist's ideal distribution of reserves. However, economic research could identify mechanisms that leverage the comparative advantage of all existing public lands. In some cases, public land would be redesignated as a core reserve. In other cases, public land could be used to gain the cooperation of independent landowners within a particular multiple use module, possibly by opening some areas of public land to commercial activities of cooperating landowners. Using

public land as a tool to gain landowner cooperation may ultimately reduce the opportunity costs, including the public administration costs, of establishing a respectable network of ecosystem reserves.

Both conservation biology and economics raise important ironies. Ecology (e.g., Tilman 1996) shows that biologically diverse ecosystems may *not* further preservation of individual species, while economics (e.g., Hoehn and Randall 1989) suggests that holistic valuation may lead to less public support for conservation, as compared with traditional (and flawed) benefit-cost analysis. For economists, an understanding of conservation biology is critical to effective contributions. Both economists and biologists object to piecemeal attempts to value ecosystem attributes separately, because oversimplification biases investment toward excessive restrictions and biases management away from ecosystem attributes that are excluded or poorly correlated with, for example, diversity indices retained in the analysis. However, if economists recast their role in terms of service to ecosystem managers—or conservation biologists—as clients, presenting sound analysis in a form that aids managers in achieving their goals and in understanding factors affecting public support for those goals, economists may find a more sympathetic audience and begin to make more effective contributions to ecosystem management.

References

Albers, Heidi J. 1996. "Modeling Ecological Constraints on Tropical Forest Management: Spatial Interdependence, Irreversibility, and Uncertainty." *Journal of Environmental Economics and Management* 30(1):73–94.

Arrow,Kenneth, Bert Bolin, Robert Costanza, Partha Dasgupta, Carl Folke, C.S. Holling, Bengt-Owe Jansson, Simon Levin, Karl-Göran Mäler, Charles Perrings, and David Pimentel. 1995. "Economic Growth, Carrying Capacity, and the Environment." *Science* 268 (April 28): 520–21.

Bengston, David N. 1994. "Changing Forest Values and Ecosystem Management." *Society and Natural Resources* 7(6):515–33.

Bergstrom John C., and John B. Loomis. 1995. "Economic Dimensions of Ecosystem Management." Invited paper presented to the National Conference on Human Dimensions of Ecosystem Management, December 1994, Helen, Ga. Department of Agricultural and Applied Economics, University of Georgia, Faculty Series paper FS 95-5. October.

Bingham, Gail, Richard Bishop, Michael Brody, Daniel Bromley, Edwin (Toby) Clark, William Cooper, Robert Costanza, Thomas Hale, Gregory Hayden, Stephen Kellert, Richard Norgaard, Bryan Norton, John Payne, Clifford Russell, and Glenn Suter. 1995. "Issues in Ecosystem Valuation: Improving Information for Decision Making." *Ecological Economics* 14(2):73–90.

Bishop, Richard C. 1978. "Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard." *American Journal of Agricultural Economics* 60(1):10–18.

———. 1979. "Endangered Species, Irreversibility, and Uncertainty: A Reply." *American Journal of Agricultural Economics* 61(2):376–79.

Bowes, Michael D., and John V. Krutilla. 1989. *Multiple-Use Management: The Economics of Public Forestlands.* Washington, D.C.: Resources for the Future.

Boyd, R. 1984. "Government Support of Nonindustrial Production: The Case of Private Forests." *Southern Economic Journal* 51(1):89–107.

Bromley, Daniel W. 1989. "Entitlements, Missing Markets, and Environmental Uncertainty." *Journal of Environmental Economics and Management* 17(2):181–94.

———. 1990. "The Ideology of Efficiency: Searching for a Theory of Policy Analysis." *Journal of Environmental Economics and Management* 19(1):86–107.

Brunson, Mark, and Bo Shelby. 1992,. "Assessing Recreational and Scenic Quality: How Does New Forestry Rate?" *Journal of Forestry* 90(7):37–41.

Burton, Peter S. 1996. "Land Use Externalities: Mechanism Design for the Allocation of Environmental Resources." *Journal of Environmental Economics and Management* 20(2):174–85.

Comanor, Joan M. 1994. "Ecosystem Management and Its Influence on Private Forest Landowners." Paper presented to the Society of American Foresters, September 18–22, Anchorage, Alaska. [Available on the Internet: (http://222.fs.fed.us/land/comano1.html].

Crocker, Thomas D., and John Tschirhart. 1992. "Ecosystems, Externalities, and Economies." *Environmental and Resource Economics* 2(6):551–67.

Fisher, Anthony C., . Michael Hanemann, and Andrew G. Keeler. 1991. "Integrating Fishery and Water Resource Management: A Biological Model of a California Salmon Fishery." *Journal of Environmental Economics and Management* 20(3):234–61.

Flick, Warren A., and William E. King. 1995. "Ecosystem Management as American Law." *Renewable Resources Journal* 13(3):6–11.

Franklin, Jerry. 1989. "Toward a New Forestry." *American Forests* 95(11/12):37–44.

Franklin, J.F., and R.T.T. Forman. 1987. "Creating Landscape Patterns by Forest Cutting: Ecological Consequences and Principles." *Landscape Ecology* 1(1):5–18.

Gale, Richard P., and Sheila M. Cordray. 1991. "What Should Forests Sustain? Eight Answers." *Journal of Forestry* 89(5):31–36.

Gillis, Anna Maria. 1990. "The New Forestry: An Ecosystem Approach to Land Management." *Bioscience* 40(8):558–62.

Gottfried, Robert, David Wear, and Robert Lee. 1996. "Institutional Solutions to Market Failure on the Landscape Scale." *Ecological Economics*. In press.

Grumbine, R. Edward. 1994. "What Is Ecosystem Management?" *Conservation Biology* 8(1):27–38.

Hagan, John M. 1995. "Environmentalism and the Science of

Conservation Biology." *Conservation Biology* 9(5):975–76.

Hahn, Robert W. 1989. "A New Approach to the Design of Regulation in the Presence of Multiple Objectives." *Journal of Environmental Economics and Management* 17(2): 195–211.

Helfand, Gloria E., and Jonathan Rubin. 1994."Spreading versus Concentrating Damages: Environmental Policy in the Presence of Nonconvexities." *Journal of Environmental Economics and Management* 27(1):84–91.

Hoehn, John P. 1991. "Valuing the Multidimensional Impacts of Environmental Policy: Theory and Methods." *American Journal of Agricultural Economics* 73(2):289–99.

Hoehn, John P. and Alan Randall. 1989. "Too Many Proposals Pass the Benefit Cost Test." *American Economic Review* 79(3):544–51.

Hof, John G., and Linda A. Joyce. 1992. "Spatial Optimization for Wildlife and Timber in Managed Forest Ecosystems." *Forest Science* 38(3):489–508.

Holland, David N., Robert J. Lilieholm, David W. Roberts, and J. Keith Gilless. 1994. "Economic Trade-offs of Managing Forests for Timber Production and Vegetative Diversity." *Canadian Journal of Forest Research* 24(6): 1260–65.

Holling, C.S., and Gary K. Meffe. 1996. "Command and Control and the Pathology of Natural Resource Management." *conservation Biology* 10(2):328–37.

Hunter, Malcolm L., Jr. 1990. *Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity.* Englewood Cliffs, N.J.: Prentice Hall.

Hyberg, B., and D. Holthausen. 1989. "The Behavior of Nonindustrial Private Forest Owners." *Canadian Journal of Forest Research* 19(8):1014–23.

Iverson, David C., and Richard M. Alston. 1993. "Ecosystem-Based Forestry Requires a Broader Economic Focus." *Journal of Sustainable Forestry* 1(2):97–106.

Kangas, Jyrki, and Jussi Kuusipalo. 1993. "Integrating Biodiversity into Forest Management Planning and Decision-Making." *Forest Ecology and Management* 61(1/2):1–15.

Koskela, E. 1989. "Forest Taxation and Timber Supply under Price Uncertainty: Credit Rationing in Capital Markets." *Forest Science* 35(1):160–72.

Kuuluvainen, Jari, Heimo Karppinen, and Ville Ovaskainen. 1996. "Landowner Objectives and Nonindustrial Private Timber Supply." *Forest Science*. In press.

Kuuluvainen, J., and J. Salo. 1991. "Timber Supply and Life Cycle Harvest of Nonindustrial Private Forest Owners: An Empirical Analysis of the Finnish Case." *Forest Science* 37(4):1011–29.

Lélé, Sharachchandra, and Richard B. Norgaard. 1996. "Sustainability and the Scientist's Burden." *Conservation Biology* 10(2):354–65.

Linddal, Michael. 1996. "Costs and Benefits of Temperate Forest Certification." *Proceedings of the Biennial Meeting of the Scandinavian Society of Forest Economics, Mekrijärvi, Finland,* March 19–21. In press.

Lippke, Bruce, and Chadwick D. Oliver. 1993. "Managing for Multiple Values: A Proposal for the Pacific Northwest." *Journal of Forestry* 91(12):14–18.

MacArthur, R.H., and J.W. MacArthur. 1961. "On Bird Species Diversity." *Ecology* 42(3):594–98.

Max, W., and D. Lehman. 1988. "A Behavioral Model of Timber Supply." *Journal of Environmental Economics and Management* 15(1):71–86.

Mendelsohn, Robert. 1995. "An Economic-Ecological Model for Ecosystem Management." In *Forestry, Economics and the Environment,* ed. W.L. Adamowicz, P. Boxall, M.K. Lucker, W.E. Phillips, and W.A. White, 213–21. Wallingford, U.K.: CAB International.

Metrick, Andrew, and Martin L. Weitzman. 1996. "Patterns of Behavior in Endangered Species Preservation." *Land Economics* 72(1):1–16.

Moffat, Anne Simon. 1996. "Biodiversity Is a Boon to Ecosystems, Not Species." *Science* 271 (March 15):1497.

Montgomery, Claire A., Gardner M. Brown, Jr., and Darius M. Adams. 1994. "The Marginal Cost of Species Preservation: The Northern Spotted Owl." *Journal of Environmental Economics and Management* 26(2):111–28.

Murray, Brian C., and David N. Wear. 1996. "Assessing the Scope for Inter-regional Product Substitutions from Regional Timber Supply Shocks." Draft manuscript. Research Triangle Institute, Research Triangle Park, N.C. May.

Newman, David H., and David N. Wear. 1993. "Production Economics of Private Forestry: A Comparison of Industrial and Nonindustrial Forest Owners." *American Journal of Agricultural Economics* 75(3):674–84.

Niese, Jeffrey Neal, and Terry F. Strong. 1992. "Economics and Tree Diversity Trade-offs in Managed Northern Hardwoods." *Canadian Journal of Forest Research* 22(11): 1807–13.

Noss, Reed F. 1990. "Indicators for Monitoring Biodiversity: A Hierarchical Approach." *Conservation Biology* 4(4): 355–64.

Noss, Reed F., and Allen Y. Cooperrider. 1994. *Saving Nature's Legacy: Protecting and Restoring Biodiversity.* Washington, D.C.: Island Press.

Opaluch, James J., and Kathleen Segerson. 1989. "Rational Roots of 'Irrational' Behavior: New Theories of Economic Decision-Making." *Northeastern Journal of Agricultural and Resource Economics* 18(2):81–95.

Parks, Peter J., and Randall A. Kramer. 1995. "A Policy Simulation of the Wetlands Reserve Program." *Journal of Environmental Economics and Management* 28(2):223–40.

Paulsen, Charles M., and Kris Wernstedt. 1995. "Cost-Effectiveness Analysis for Complex Managed Hydrosystems: An Application to the Columbia River Basin." *Journal of Environmental Economics and Management* 28(3): 388–400.

Polasky, Stephen, and Andrew R. Solow. 1995. "On the Value of a Collection of Species." *Journal of Environmental Economics and Management* 29(3):298–303.

Provencher, Bill, and Stephen K. Swallow. 1995. "Timber Rotations on Non-Industrial Private Forests: The Owner's Wealth Constraint and Access to Ecosystems." Working paper. July.

Randall, Alan. 1994. "Thinking about the Value of Biodiversity." In *Biodiversity and Landscape,* ed. K.C. Kim and R.D. Weaver. New York: Cambridge University Press.

Randall, Alan, and Michael C. Farmer. 1995. "Benefits, Costs, and the Safe Minimum Standard of Conservation."

In *The Handbook of Environmental Economics*, ed. Daniel W. Bromley, 26–44. Oxford: Blackwell.

Ready, Richard C., and Richard C. Bishop. 1991. "Endangered Species and the Safe Minimum Standard." *American Journal of Agricultural Economics* 73(2):309–12.

Roan, Philip F., and Wade E. Martin. 1996. "Optimal Production and Reclamation at a Mine Site with an Ecosystem Constraint. *Journal of Environmental Economics and Management* 30(2):186–98.

Rubin, J., G. Helfand, and J. Loomis. 1991. "A Benefit-Cost Analysis of the Northern Spotted Owl." *Journal of Forestry* 89(12):25–30.

Ruitenbeek, H. Jack. 1992. "The Rainforest Supply Price: A Tool for Evaluating Rainforest Conservation Expenditures." *Ecological Economics* 6(1):57–78.

Sagoff, Mark. 1994. "Should Preferences Count?" *Land Economics* 70(2):127–44.

Sample, V. Alaric. 1994. "Building Partnerships for Ecosystem Management on Mixed Ownership Landscapes." *Journal of Forestry* 92(8):41–44.

Sedjo, Roger A. 1995a. "Toward an Operational Definition of Ecosystem Management." Paper presented to the Workshop on Analysis in Support of Ecosystem Management. April 10–13, Fort Collins, Colo.

———.1995b. "Ecosystem Management: An Uncharted Path for Public Forests." *Resources* no. 121(fall):10,18–20.

———. 1996a. "Toward an Operational Approach to Public Lands Ecosystem Management." *Journal of Forestry*. In press.

———. 1996b. "Environmental Impacts of Forest Protection: Some Complications." Paper presented to the International Seminar on Forest Industries toward the Third Millennium: Economic and Environmental Challenges. European Forestry Institute and University of Joensuu, March 18, Joensuu, Finland.

Simpson, R. David, and Roger A. Sedjo. 1996. "Investments in Biodiversity Prospecting and Incentives for Conservation." Discussion Paper 96-14. Washington, D.C.: Resources for the Future. April.

Simpson, R. David, Roger A. Sedjo, and John W. Reid. 1996. "Valuing Biodiversity for Use in Pharmaceutical Research." *Journal of Political Economy* 104(1):163–85.

Smith, V. Kerry, and John V. Kurtilla. 1979. "Endangered Species, Irreversibilities, and Uncertainty: A Comment." *American Journal of Agricultural Economics* 61(2):371–75.

Solow, Andrew R., Stephen Polasky, and James M. Broadus. 1993. "On the Measurement of Biological Diversity." *Journal of Environmental Economics and Management* 24(1):60–68.

Stanley, Thomas R., Jr. 1995. "Ecosystem Management and the Arrogance of Humanism." *Conservation Biology* 9(2): 255–62.

Sullivan, Francis. 1996. "Independent Certification of Forests and Forest Products." Paper presented to the International Seminar on Forest Industries Toward the Third Millennium: Economic and Environmental Challenges. European Forestry Institute and University of Joensuu, March 18, Joensuu, Finland.

Swallow, Stephen K. 1994. "Renewable and Nonrenewable Resource Theory Applied to Coastal Agriculture, Forest, Wetland, and Fishery Linkages." *Marine Resource Economics* 9(4):291–310.

______. 1996. "Resource Capital Theory and Ecosystem Economics: Developing Nonrenewable Habitats of Heterogeneous Quality." *Southern Economic Journal* 63(1):106–23.

Swallow, Stephen K., Piyali Talukdar, and David N. Wear. n.d. "Spatial and Temporal Specialization in Forest Ecosystem Management under Sole Ownership." *American Journal of Agricultural Economics*. In press.

Swallow, Stephen K., and David N. Wear. 1993. "Spatial Interactions in Multiple-Use Forestry and Substitution and Wealth Effects for the Single Stand." *Journal of Environmental Economics and Management* 25(2):103–20.

Swallow, Stephen K., Thomas F. Weaver, Lynn A. Smith, and Robert J. Johnston. 1995. "Designing Environmental Programs: Policy-Relevant Payment Vehicles and In-Kind Tradeoffs in Watershed Management Plans." Paper presented at the Annual Meetings of the American Agricultural Economics Association and the Association of Environmental and Resource Economists. August 6–9, Indianapolis, Ind.

Tilman, David. 1996. "Biodiversity: Population Versus Ecosystem Stability." *Ecology* 77(2):350–63.

Turner, Monica G. 1989. "Landscape Ecology: The Effect of Pattern on Process." *Annual Review of Ecology and Systematics* 20:171–97.

Vincent, Jeffrey R. and Clark S. Binkley. 1993. "Efficient Multiple-Use Forestry May Require Land-Use Specialization." *Land Economics* 69(4):370–76.

Wear, David N. 1992. "Forest Management, Institutions, and Ecological Sustainability." *Proceedings of the Appalachian Society of American Foresters Meeting, Asheville, NC* 12–16.

Wear, David N., Monica G. Turner, and Richard O. Flamm. 1996. "Ecosystem Management in a Multi-Ownership Setting: Exploring Landscape Dynamics in a Southern Appalachian Watershed." *Ecological Applications*. In press.

Weitzman, Martin L. 1992. "On Diversity." *Quarterly Journal of Economics* 107(2):363–406.

______. 1993. "What to Preserve? An Application of Diversity Theory to Crane Conservation." *Quarterly Journal of Economics* 108(1):157–83.

Windsor, Donald A. 1995. "Equal Rights for Parasites." *Conservation Biology* 9(1):1–2.