Using Sciences to Improve the Economic Efficiency of Conservation Policies

JunJie Wu

In the last 20 years, both public and private expenditures on resource conservation and environmental protection have increased dramatically. However, there are numerous technical and political barriers to the efficient use of conservation funds. This paper discusses some of these barriers and approaches to overcoming them. It argues that ecosystem complexities such as threshold effects, ecosystem linkages, and spatial connections often mitigate against politically palatable criteria for resource allocation. Ignoring these complexities is likely to result in substantial efficiency losses. While challenges are daunting for the efficient management of conservation investments, payoff is potentially high for the use of sciences.

Key Words: conservation policies, distributional effects, ecosystem linkages, spatial connections, targeted policies, threshold effects

In the last 20 years, federal expenditures on agricultural conservation programs have increased significantly in the United States, from about $750 million in the early 1980s to over $2.5 billion in recent years (Claassen et al., 2001). This trend of increasing conservation expenditures continued with the 2002 Farm Bill, which not only reauthorized some of the most important conservation programs in U.S. history (e.g., Conservation Reserve Program, Environmental Quality Incentive Program, and Wetlands Reserve Program), but also included provisions for new conservation programs (e.g., Conservation Security Program, Grassland Reserve Program).

With the increasing expenditures on conservation, a number of important issues have been raised, including: How should conservation funds be allocated among geographic areas? Should funds be concentrated in fewer watersheds or distributed over a wider geographic area? Should funding priorities be given to areas with the worst environmental problems, or to areas that have made some environmental improvements? What criteria should be used to target resources for conservation? Should conservation programs target least expensive resources or resources that are most vulnerable to environmental damage? If farmers are paid for conservation, what should payments be based on?—i.e., should payments be based on the adopted conservation practices or the amount of environmental benefits provided? What are the economic, environmental, and distributional implications of alternative targeting criteria? These issues are not only intellectually challenging, but also policy relevant.

In this paper, I review some of the recent work addressing these issues. I argue that ecosystem complexities such as threshold effects, ecosystem linkages, and spatial connections often mitigate against politically palatable criteria for resource allocation. Ignoring these complexities is likely to result in substantial losses in economic efficiency.

While challenges are daunting to incorporate these complexities into the design of conservation policies, payoffs are potentially high. I propose a two-stage procedure for the design of conservation programs and argue that such a two-stage procedure can reduce the information requirement for the efficient targeting of conservation efforts.

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The remainder of this paper is organized as follows. First, a discussion is presented to highlight several strategies for conservation targeting and their economic, environmental, and distributional implications. I then explain why it is so challenging to design and implement an efficient conservation program in the presence of threshold effects, ecosystem linkages, and spatial connections between ecosystems. Case studies are then reviewed, examining the extent to which conservation funds would be misallocated when these ecosystem complexities are ignored, and exploring how sciences can be used to improve the economic efficiency of conservation programs. The presentation ends with a few concluding remarks.

Conservation Targeting Strategies

Consider the problem of a conservation program manager who wants to target some resources (e.g., land) for conservation. Depending on the objectives of the conservation program, the program manager can choose among several targeting strategies, including:

- *Benefit-Cost Targeting.* Targeting of resources that provide the highest benefit-cost ratios. In recent CRP signups, bids were accepted based on the Environmental Benefits Index, which considers both environmental benefits and economic costs.
- *Benefit-Maximizing Targeting.* Targeting of resources that provide the largest environmental benefit for a given budget. This is the stated objective of several recent conservation programs, including the Environmental Quality Incentive Program.
- *Benefit Targeting.* Targeting of resources that provide the highest environmental benefit per resource unit. For example, the U.S. Fish and Wildlife Service tends to target wetlands and other resources based on biological criteria.
- *Cost Targeting.* Targeting of least expensive resources. Reicheldefer and Boggess (1988) suggest the targeting criterion for the initial CRP signups is consistent with this targeting criterion.

In a recent paper, Wu, Zilberman, and Babcock (2001) compared the economic, environmental, and distributional impacts of these four targeting strategies for a heterogeneous resource base where both the environmental benefits and opportunity costs can be measured for individual resource units when they are preserved. They found that if the ultimate objective of conservation is to maximize social welfare, which is defined as the sum of consumer surplus, producer surplus, and environmental benefits, then benefit-cost targeting should be used. In other words, the program manager should rank individual resource units according to the benefit-cost ratios and accept resources into the program until the budget is exhausted.

The benefit-cost targeting strategy, however, does not provide the largest environmental benefit for a given conservation budget if the output demand is not perfectly elastic. To maximize the total environmental benefit for a given conservation budget, the program manager must target more high-benefit and high-cost resources than under the benefit-cost targeting strategy. Doing so, the program manager would be able to achieve the same level of environmental benefit for a smaller reduction in total output because the highly productive resources have a large profit margin. A smaller reduction in total output would reduce the increase in output prices and program costs. In essence, the program manager acts like a monopsonist, who realizes that by purchasing more high-benefit and high-output resources than under cost-benefit targeting, she can reduce the increase in output prices. A lower output price means lower purchasing costs and a smaller slippage (i.e., fewer acres of non-cropland would be converted to cropland as a result of output price increases).

In contrast to benefit-cost targeting, benefit targeting attempts to preserve resources providing the highest environmental benefit per resource unit. Because this strategy ignores costs, it takes the smallest amount of resources out of production. As a result, it has the smallest impact on output prices among the four strategies. Consumers should prefer this strategy as it results in larger consumer surplus than the other three strategies. Further, because this strategy has the smallest impact on production, it may also be supported by other interest groups, including labor and input suppliers. Benefit targeting should be the least preferred strategy of the resource owners because it results in the lowest producer surplus.

Under the cost-targeting strategy, the least-cost resources are preserved first. Consequently, it takes the largest amount of resources out of production. Resource owners should prefer this strategy because it leads to the largest increase in output prices and producer surplus. Incidentally or not, the Conservation Reserve Program used this targeting before 1992 to provide both environmental benefit and farm income support.

Challenges in the Design of Conservation Policies

As suggested by the above analysis, if both the benefits and costs of conservation on individual resource units can be accurately measured, then a strategy which targets resources with the highest benefit-cost ratios will be socially optimal in the sense that it maximizes the social welfare for a given conservation budget. However, in many cases, it is difficult to measure conservation benefits for individual resource units in isolation. Because of ecosystem complexities, such as threshold effects, ecosystem linkages, and spatial connections of watersheds, benefits of conservation on different resource units are not independent of one another. These complexities require the adoption of a system approach when designing conservation policies.

However, because of lack of information, U.S. conservation programs have historically been designed to protect specific resources, managed by different agencies, and targeted based on on-site, productivity-related criteria (Ribaudo, 1986). Such a piecemeal approach tends to ignore the ecosystem complexities such as threshold effects, ecosystem linkages, and spatial connections of watersheds. This section provides a review of some of the studies that address these issues, with discussion focusing on how conservation should be targeted in the presence of these ecosystem complexities.

Threshold Effects

A threshold effect is present when a significant environmental improvement can be achieved only after conservation efforts reach a certain threshold. For example, to protect a cold-water fish species, stream temperature must be reduced below a certain level. Wu and Boggess (1999) developed a theoretical framework to analyze the effect of threshold effects on the targeting of conservation efforts. They found that targeting conservation efforts based on physical criteria or political equity concerns tends to ignore the threshold effects of conservation efforts, which may cause conservation funds to be overly dispersed geographically and, as a result, may yield minimum environmental benefits when the budget is small. When funds are insufficient to address environmental problems in all areas, they should be concentrated in selected areas rather than be spread over a large region. The selection of areas for funding should be based on both the sources of environmental problems and the seriousness of the problems.

Threshold effects have been identified in many conservation efforts, particularly those involving fish and wildlife. For example, Lamberson et al. (1992) reported there is a significant threshold effect in the relationship between the northern spotted owl survival and suitable habitat. When suitable habitat is less than 10% of landscape, the chance for northern spotted owl to survive would be zero; however, when suitable habitat reaches 15% of the landscape, the chance of survival would reach 80%, and when suitable habitat reaches 20% of the landscape, the chance of survival would reach 95%. This nonlinear relationship suggests that if conservation funds are divided equally between two watersheds and the funds are only sufficient to restore 10% of landscape in each watershed, then no benefit would be received. But if all of the funding is concentrated in one watershed, and 20% of the landscape is protected, then the chance of survival in that watershed would reach 95%. This simple example shows that when threshold effects are ignored, funds tend to be overly dispersed geographically.

In an empirical analysis, Wu, Adams, and Boggess (2000) analyzed the consequences of ignoring the threshold effect in the context of an important habitat management issue in the Pacific Northwest—preserving wild stocks of steelhead trout. This analysis confirms the presence of threshold effects in habitat investments within a case study watershed, the John Day River basin, Oregon. Based on the findings of their study, allocation of funds according to typical allocation rules or guidelines will not be efficient in the presence of these threshold effects. For example, allocation of funds equally across two sub-basins within the basin would not yield equal payoff in terms of enhanced trout production. More striking is the finding that even within a relatively small sub-basin or stream, the benefits of habitat investments vary markedly, depending on the condition of surrounding habitat. These results, although exploratory in nature, point to the need to manage habitat and other conservation investments in ways which recognize the complexity of the system.

Wu and Skelton-Groth (2002) extended the Wu, Adams, and Boggess analysis to 13 streams in the John Day River Basin and explored the importance of considering both the threshold effects and ecosystem linkages. They found that a large portion of conservation benefits would be lost when threshold effects and correlated benefits are ignored. Therefore, Wu and Skelton-Groth argue that funds should be allocated whereby the total value of environmental benefits is maximized—not the total amount of resources protected.

In the presence of threshold effects, conservation targeting should take a two-stage procedure. In the first stage, conservation funds are allocated among watersheds. In the second stage, resources within each watershed are targeted for conservation. In making fund allocation across watersheds, the program manager should make sure conservation efforts are above the threshold levels before expanding to new watersheds. She should also determine that the marginal benefits of conservation expenditures are identical across watersheds. This would require the program manager to compare the values of conservation benefits across watersheds. However, as shown in Wu and Boggess (1999), even if conservation generates multiple benefits, the program manager only needs to compare the relative values of one benefit across watersheds as long as appropriate resources are targeted within each watershed.

In targeting resources for conservation within a watershed, a program manager should rank resource units according to benefit-cost ratios and accept resources into the program until the budget is exhausted. However, with the two-stage procedure, the benefit can be measured using an on-site physical criterion, such as tons of soil erosion reduced or miles of riparian buffers established, without the need for information about the social value of environmental benefits if the social value is an increasing function of the physical measure. Thus, a major advantage of this two-stage framework is that information on the social values of conservation benefits is not required for the optimal targeting of conservation efforts within a watershed.

Ecosystem Linkages

The second problem with the piecemeal approach of conservation policy is that it ignores the relationships between alternative environmental benefits. Such relationships can take two forms: interactions or correlations (Wu and Boggess, 1999). The interaction refers to the cause-effect relationships among alternative environmental benefits. For example, improving water quality enhances fish habitat. The correlation refers to the situation where two environmental benefits are jointly produced by the same conservation effort, although these two benefits have no cause-effect relationship. Citing another illustration, the CRP reduces soil erosion by retiring lands from crop production; it also reduces groundwater pollution, although groundwater pollution and soil erosion have no direct cause-effect relationship.

In their examination of the effect of ecosystem linkages on the targeting of conservation efforts, Wu and Boggess (1999) found that ignoring the interaction between different environmental benefits would not lead to misallocation of conservation funds only under very restrictive conditions. For example, if the relationships between different benefits are the same across watersheds, then misallocation would not occur only when (*a*) all benefits are proportional to one another, (*b*) the targeted benefit is the same across the watersheds, or (*c*) all funds are allocated to one watershed. Otherwise, misallocation would occur. Specifically, if the direct benefit increases the indirect benefit at an increasing (decreasing) rate, targeting only a direct benefit would over- (under-) fund watersheds with a larger amount of total direct benefit. The degree of misallocation increases as the curvature of the relationship between the indirect benefit and direct benefit increases.

Ignoring the correlations between different environmental benefits would lead to both the misallocation of conservation funds across watersheds and the mistargeting of resources within individual watersheds. Targeting based on a single benefit does not lead to mistargeting of resources within a watershed only when (*a*) the budget can save much more of the targeted benefit than untargeted benefits, and/or (*b*) the social value of the targeted benefit is much larger than the social value of the untargeted benefits (Wu and Skelton-Groth, 2002).

In their case study of conservation programs for salmonids habitat restoration in the Pacific Northwest, Wu and Skelton-Groth (2002) estimated the amount of benefit losses when ecosystem linkages are ignored. Their analysis showed that when a water quality measure such as stream temperature is used to target conservation efforts for salmonids restoration, some streams which provide no fish benefits would be targeted. Similarly, if the fund managers target only the cold-water fish species, in order to increase their numbers, then the cost of doing so is the decrease in the numbers of warm-water fish species. For example, for every $100 gained from increasing the numbers of cold-water fish in Granite Creek in the John Day River Basin in Oregon, there are on average four speckled dace (a warm-water species) lost. Because speckled dace is not endangered, the tradeoff favors the cold-water species. But, if the warm-water species was an endangered species, or a popular recreational fishery, the decision might not be as clear-cut.

In the presence of corrected benefits, optimal targeting of conservation efforts must satisfy the following conditions (Wu and Boggess, 1999):

$$MRS_1^{ab} = MRT_1^{ab},\ MRS_2^{ab} = MRT_2^{ab},$$
$$MV_1^{a} = MV_2^{a},\ \text{and}\ MV_1^{b} = MV_2^{b},$$

where MRS_i^{ab} is the marginal rate of substitution between benefit a and benefit b in watershed i, which measures the amount of benefit b watershed i is willing to give up for a unit of benefit a; MRT_i^{ab} is the marginal rate of tradeoff between benefit a and benefit b within watershed i, which measures the amount of benefit b watershed i must give up in order to gain one more unit of benefit a; and MV_i^j is the marginal value of benefit j of conservation expenditure in watershed i.

The above conditions suggest that information about the tradeoffs between alternative environmental benefits and their social values is required to ensure optimal targeting of conservation efforts. This type of information is difficult to obtain, and relatively little information is currently available. However, physical and biological scientists are increasingly investigating these relationships, and payoff for this information is potentially high.

Spatial Connections of Ecosystems

Ecosystems are connected spatially simply because conservation upstream affects water quality downstream. When conservation is targeted based on an on-site physical criterion, spatial linkages of ecosystems are ignored. In a recent study, Watanabe, Adams, and Wu (2003) explored the importance of spatial linkages in the targeting of conservation efforts in the upper Grande Ronde River Basin in Oregon. Based on their findings, the heterogeneous nature of riparian conditions and stream morphology must be considered to allocate restoration activities efficiently. Localized effects of restoration efforts on water quality are important to achieve small water quality improvement. However, as the desired water quality standard increases, the cumulative (longitudinal) effects become more important, and restoration efforts in more distant reaches may be more efficient than efforts nearer the point of monitoring. The spatial allocation of conservation efforts depends on the water quality standard if the objective is to maximize the stream length where the standard is met. Yet, if the underlying objective is to increase fish populations, targeting conservation efforts based on the water quality standard may lead to substantial benefit losses. These results suggest that in the presence of spatial connections and ecosystem linkages, a system approach must be adopted when targeting resources for conservation.

Concluding Comments

In most conservation investments, there are likely some strong nonlinearities, ecosystem linkages, and spatial connections which mitigate against the politically palatable criteria for resource allocation. Management of habitat investments must recognize these complexities of ecosystems. In the presence of these ecosystem complexities, a two-stage procedure for policy design should be used. In the first stage, conservation funds are allocated among watersheds to make certain the threshold effect is reached; in the second stage, resources within each watershed are targeted for conservation. Such a two-stage procedure not only can take into account some of the ecosystem complexities, but may also reduce the information requirements for the optimal targeting of conservation efforts within a watershed.

Policy designs that ignore ecosystem complexities, or formulas based on political consideration, or keyed to a specific on-site physical criterion, are likely to result in substantial losses in economic efficiency. While challenges are daunting for the efficient management of conservation investments, payoff is potentially high when sciences are used in the design of conservation programs.

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