The Economics of Conservation Targeting Strategies*

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This is an abbreviated version of a paper published in the
American Journal of Agricultural Economics, Vol. 82 #2, pages 400-413.

Abstract: In recent years, payments to purchase resources or easements or to change landowner behavior have become a major vehicle for resource conservation and environmental protection. These funds use various strategies to target resources for conservation, the choice of which may lead to striking differences in economic and environmental performance. In this presentation, we present an analytic framework to evaluate the economic, environmental and distributional impacts of alternative targeting strategies. We argue that the prevailing U.S. federal policy of targeting conservation programs on the basis of onsite criteria ignores threshold effects in resource conservation, which may cause conservation funds to be overly dispersed geographically and result in substantial losses in economic efficiency.

We show that when funds are insufficient to correct environmental problems in all areas, they should be concentrated in selected target areas. The empirical focus is on habitat investments to protect an important anadromous fish species in the Pacific Northwest, steelhead trout. Results of the analysis point to a substantial cumulative effect in the relationship between water quality and abundance in this fishery, which affects the efficiency of specific habitat investments

U.S. conservation programs have historically been designed to protect specific resources, managed by different agencies, and targeted on the basis of onsite physical criteria, such as soil erosion rates, rather than on the values of environmental benefits provided (Ribaudo). One problem with this piecemeal approach is that it ignores what is often a cumulative or threshold effect in environmental quality management (Wu and Boggess). Such effects exist when a significant environmental improvement (e.g., water quality becomes suitable for swimming or fish survival) can be achieved only after conservation efforts reach a certain threshold. Cumulative effects exist in many conservation efforts, particularly those involving fish and wildlife. For example, cumulative effects have been identified in the protection of endangered species (Lamberson et al.), in preserving biodiversity (White et al.; Fahrig and Merriam), and in increasing salmonid production (Adams et al.; Li et al.). Ignoring cumulative effects may cause conservation funds to be overly dispersed geographically and, as a result, produce the minimum environmental benefit when a conservation budget is small (Wu and Boggess).

The implications of cumulative effects for the allocation of conservation management funds are substantial, since billions of dollars are spent on conservation programs each year. The Conservation Reserve Program (CRP), one of the largest conservation programs in U.S. history, targets highly erodable land with an annual budget of over $1.7 billion in 1997 (Economic Research Service, p. 262). The Environmental Quality Incentive Program, established in the Federal Agriculture Improvement and Reform Act of 1996, targets “geographic priority areas” to “maximize environmental benefits per dollar expended”, with an authorized budget of $1.3 billion (Natural Resource Conservation Service). In October 1998, the federal government and the states of Oregon and Washington joined in an initiative to restore freshwater streams that provide habitat for salmon and trout listed under the Federal Endangered Species Act. The initiative expands an existing program, the Conservation Reserve Enhancement Program (CREP), by allowing up to 200,000 acres of riparian land along up to 7,000 miles of salmon and trout streams throughout Oregon and Washington to be restored (U.S. Department of Agriculture).

The objective of this study is to investigate the importance of cumulative effects in the allocation of conservation funds. The empirical focus is on habitat investment to protect an important anadromous fish species in the Pacific Northwest, steelhead trout (*Oncorhynchus mykiss*). Steelhead are a sea-run subspecies of rainbow trout, which are indigenous to the Pacific Northwest, ranging from central California to southern Alaska. As with other anadromous salmonids, they spend part of their life in freshwater streams, but most of their adult life in the ocean. Unlike the five species of Pacific salmon, steelhead do not die after spawning. The economic and cultural importance of this species derives primarily from sport fishing, native American harvests, and Endangered Species Act (ESA) considerations, as commercial harvests of steelhead are prohibited (Adams et al.).

A case study is conducted to analyze the impact of habitat investments on steelhead abundance using biological, hydrologic, and economic data collected for the John Day River Basin in central Oregon, a river basin where substantial habitat investments to improve anadromous fish production are underway. The analysis assesses the extent to which conservation funds for habitat enhancements would be misallocated within the basin if cumulative effects are ignored. The empirical analysis is intended as an exploratory demonstration of the importance of the cumulative effects in conservation fund allocation, rather than to provide a comprehensive assessment of a particular policy.

Several studies have estimated the effect of habitat investments on fish abundance. Adams et al. and Johnson and Adams estimated costs and benefits of selected fishery habitat restoration efforts in the John Day River, but did not consider cumulative effects. Li et al. examined the effect of riparian canopy on the production of rainbow trout in the same river system and found that rainbow trout abundance is negatively correlated with maximum stream temperature and solar insolation, and positively correlated with bank stability and vegetation stability. Harpman et al. estimated changes in the number of adult brown trout under alternative flow regimes of the Taylor River, Colorado. Again, these studies did not examine the threshold effect and its implication on the optimal spatial distribution of conservation efforts.

Several studies have examined approaches to improving the efficiency of conservation programs, but none have considered cumulative effects. Ribaudo analyzed CRP targeting using both onsite and offsite benefits and found that ignoring offsite benefits leads to an inefficient allocation of resources because of the large differences in the ratio of offsite to onsite benefits across regions. Ribaudo, however, assumed that marginal values of environmental benefits are constant (no cumulative effects) and identical among watersheds in a given region (e.g., the Corn Belt). A similar assumption was made by Pimental et al. in the analysis of soil erosion costs and conservation benefits.

Modeling Allocation Decisions in the Presence of Cumulative Effects

The economic benefits arising from a conservation program or environmental regulation are often determined by a complex chain of relationships. For example, to estimate the effect of a program such as the CREP on steelhead trout production in the Pacific Northwest, one would have to estimate 1) conservation practices (e.g., miles of vegetated riparian corridors) established under the program, 2) the effects of these conservation practices on stream water temperature and other habitat characteristics, and 3) the effects of the changes in habitat characteristics on recruitment for the species of interest. Because it is much easier to estimate miles of riparian corridors established or tons of soil saved than to estimate the number of fish saved, previous conservation programs, including CRP and EQIP, have used onsite physical measures such as tons of soil erosion reduced or miles of stream protected as a targeting criterion. In this section, we show that this targeting criterion would result in a misallocation of conservation funds for protecting salmonid habitats in the Pacific Northwest.

There are a range of management alternatives for improving trout habitat. These include establishing riparian canopy and fencing to protect streamside vegetation (Adams et al.). Let *R* be the miles of riparian corridors established. The environmental benefit of such a habitat investment may vary with location. However, in order to focus on fund allocation between watersheds, we assume there is a one-to-one relationship between the investment and the total environmental benefits within a given watershed: $B_i = B_i(R_i)$, where B_i is the total environmental benefit achieved in watershed *i* (e.g., the number of fish produced). For many fish or wildlife resources, it is reasonable to assume that the marginal benefit of the habitat investment $MB_i \equiv B_i'(R_i)$ is close to zero when R_i is low because the cumulative effect is not large enough to have a significant impact on water quality or habitat, and then increases rapidly as it approaches a threshold where, for example, water quality becomes suitable for trout reproduction and survival.

Consider the case of fund allocation between two watersheds. The extent of conservation practices (habitat investments) in each watershed depends on the amount of money allocated to the watershed: $R_i = R_i(M_i)$, where M_i is the amount of conservation fund allocated to watershed *i*. It is assumed that the amount of habitat protected will increase with the budget (i.e., $MR_i \equiv R_i'(M_i) \geq 0$) but at a nonincreasing rate (i.e., $R_i''(M) \leq 0$).

When a conservation program uses an onsite physical measure, such as miles of fence established, as a targeting criterion, the fund allocation between the two watersheds is determined by solving the following maximization problem:

$$\max_{\alpha} \quad TR \equiv R_1(\alpha \overline{M}) + R_2((1-\alpha)\overline{M}) \tag{1}$$

$$s.t. \quad 0 \leq \alpha \leq 1, \tag{2}$$

where $\overline{M}$ is the conservation budget, and α is the proportion of total budget allocated to watershed 1. The first-order condition for this maximization problem is

$$R_1'(\alpha \overline{M}) - R_2'((1-\alpha)\overline{M}) + \lambda - \mu = 0, \tag{3}$$

where λ and μ are the Lagrangian parameters for the constraints in (2) and satisfy the Kuhn-Tucker conditions:

$\lambda\alpha = 0$ and $\mu(1-\alpha) = 0$. If the fund is allocated to both watersheds, then $\lambda = \mu = 0$, and (3) becomes

(4)

$$R_1'(\alpha\overline{M}) = R_2'((1-\alpha)\overline{M}),$$

Thus, to maximize total stream miles protected, the fund must be allocated such that the marginal increase in stream miles protected is identical in the two watersheds. If $R_1'(\alpha\overline{M}) > R_2'((1-\alpha)\overline{M})$, more funds should be allocated to watershed 1; and if $R_1'(\alpha\overline{M})$ is always greater than $R_2'((1-\alpha)\overline{M})$, then $\mu > 0$ from (3), and $\alpha = 1$ from the Kuhn-Tucker conditions. This implies that all money should be allocated to watershed 1. Similarly, if $R_1'(\alpha\overline{M})$ is always less than $R_2'((1-\alpha)\overline{M})$, all money should be allocated to watershed 2. When the two watersheds are identical, equal amounts of money must be allocated to the two watersheds in order to maximize the total stream miles protected.

In contrast, the fund allocation that maximizes total environmental benefits is determined by solving

(5)

$$\underset{\alpha}{Max} \quad TB \equiv B_1\left(R_1(\alpha\overline{M})\right) + B_2\left(R_2((1-\alpha)\overline{M})\right)$$

(6)

$$s.t. \quad 0 \le \alpha \le 1.$$

This maximization problem is more difficult to solve than (1) because the objective function is not always concave. The first-order necessary condition for an interior solution (i.e., $0 < \alpha < 1$) is

(7)

$$B_1'(R_1)R_1'(\alpha\overline{M}) = B_2'(R_2)R_2'((1-\alpha)\overline{M}), \text{ or}$$

(8)

$$MB_1(\alpha\overline{M}) = MB_2((1-\alpha)\overline{M}),$$

which suggests that the program should allocate money to both watersheds only when it is possible to equate the marginal environmental benefits in the two watersheds. Equation (7) reduces to (4) when the marginal environmental benefits are identical in the two watersheds (i.e., $B_1'(R_1) = B_2'(R_2)$). Even under this condition, the fund allocation that maximizes total stream miles protected may not maximize total environmental benefits because the second-order condition may not be satisfied. In fact, if $B_1'(R_1) = B_2'(R_2)$ and $B_1''R_1'^2 + B_2''R_2'^2 > -\left(B_1'R_1'' + B_2'R_2''\right)$, the fund allocation that maximizes total stream miles protected actually ***minimizes*** total environmental benefits because the second-order condition for benefit minimization, $\partial^2 TB/\partial\alpha^2 = (B_1''R_1'^2 + B_2''R_2'^2) + \left(B_1'R_1'' + B_2'R_2''\right) > 0$, is satisfied. The term $B_1''R_1'^2 + B_2''R_2'^2 = \left(\partial B_1'/\partial M_1\right)R_1' + \left(\partial B_2'/\partial M_2\right)R_2'$ is the increase in marginal benefits due to the cumulative effect, and the term $(B_1'R_1'' + B_2'R_2'') = B_1'\left(\partial R_1'/\partial M_1\right) + B_2'\left(\partial R_2'/\partial M_2\right)$ is the decrease in marginal benefits due to more stream miles being protected. Thus, when there is a strong cumulative effect associated with habitat investment (i.e., $B_1''R_1'^2 + B_2''R_2'^2 > -\left(B_1'R_1'' + B_2'R_2''\right)$), the fund allocation that maximizes total stream miles protected may minimize total environmental benefits.

The above result can be illustrated by fund allocation between two identical watersheds. The conservation fund will be divided equally between two identical watersheds when the objective is to maximize total stream miles protected. This allocation minimizes the total environmental benefits when the budget is small, as illustrated in figure 1. In the figure, the distance between the two vertical axes is the total conservation budget, and any point on the horizontal axis represents an allocation of the conservation fund. A move to the right corresponds to more money being allocated to watershed 1 and less money to watershed 2. Depending on the level of budget, three cases are possible.

Figure 1a illustrates the case where the total program budget $\overline{M}$ is less than or equal to the amount of money needed to maximize total environmental benefits in one watershed M^0. When the objective is to maximize total stream miles protected, the fund would be divided equally between the two watersheds (i.e., at $0.5\overline{M}$). The total environmental benefit generated under this allocation equals $TB_{\min}$, which is the smallest under all possible allocations. In this case, total environmental benefits would be maximized if all funds are allocated to one watershed, and the opportunity cost of the misallocation equals $(TB_{\max} - TB_{\min})$.

Figure 1b illustrates the case where the total program budget $\overline{M}$ is greater than M^0 but less than $2M^m$, where M^m is the amount of money needed to maximize the marginal environmental benefit in one watershed and is defined by $\partial MB(M^m)/\partial M = 0$. When $M^0 < \overline{M} < 2M^m$, the first-order condition for benefit maximization in equation (8) has three solutions (i.e., the marginal benefit curves for the two watersheds intersect at $0.5\overline{M}$, M^* and $(\overline{M} - M^*)$). Again, an equal allocation would minimize total benefits. The optimal solution is to allocate M^* dollars to one watershed, and the rest $(\overline{M} - M^*)$ to the other. Figure 1c illustrates the case of $\overline{M} \ge 2M^m$. Only in this case, does an equal allocation of the fund maximize both the total stream miles protected and the total environment benefit.

Application to Steelhead Habitat Enhancement in the John Day River

We conducted a case study to examine the allocation of conservation funds in the presence of a potential cumulative effect. The focus is on an important fishery resource in the Pacific Northwest, steelhead trout. Over the last century, salmon and steelhead have disappeared from about 40% of their historical breeding ranges in Oregon, Washington, Idaho, and California, and many remaining populations are severely depressed in the areas where they were formerly abundant (National Research Council). Oregon streams support 12 species of anadromous and resident salmon and trout, as well as seventy other freshwater fishes native to Oregon. As of March 1999, eleven subspecies (stocks) are listed as "threatened" or "endangered" by the state and federal government, and an additional 17 species are listed as "sensitive" or "candidate" status under the ESA (State of Oregon, Oregonian).[1]

In response to these declining fish populations and to federal pressure to list more species as endangered under the ESA (including some stocks of steelhead), the state of Oregon developed the "Oregon Plan for Salmon and Watersheds" (State of Oregon). The objective is to "restore our native fish populations – and the aquatic systems that support them - to productive and sustainable levels that will provide substantial environmental, cultural, and economic benefits." As part of the effort, CREP was established in Oregon and Washington in October 1998. The program encourages landowners to establish forested buffer strips along "salmon streams", with a total budget of $500 million. The optimal allocation of these funds among watersheds requires extensive hydrological, biological and economic information.

The Study Area and Data Sources

The case study is based on data collected for the Middle Fork subbasin of the John Day river in central Oregon , as reported by Li et al. and Adams et al. The subbasin drains 2,250 km^2 and is a diverse assemblage of sedimentary, volcanic and metamorphic rock that has been uplifted and faulted to form rugged hills and maintains (Oregon Water Resource Department). This geographic setting greatly influences the stream profiles, topography and soils of the subbasins. The river channels have moderate to steep slopes. The land use is mainly forest and rangeland, with a small amount of cropland. Cattle graze the streambanks and enter the creeks in many areas. A typical landscape near the streams in the subbasin include higher-elevation forests on nearby mountains, mid-elevation rangeland on foothills, and streamside hay fields along the limited alluvial valleys (Adams et al.).

The data were collected from both the mainstem of the Middle Fork, as well as a tributary, Camp Creek, during the summer months (June – September) of 1985, 1986, 1988 and 1989. During the summer, stream temperatures reach their maximums and flows decline to base levels. Data collected in the field sampling include the number of rainbow trout by age group and hydrological and riparian characteristics (e.g., elevation, discharge, maximum and minimum stream temperatures, bank angles, canopy cover, bank stability, and soil alternation). The summary statistics for selected variables are presented in Table 1. The data set includes 64 observations, each of which represents a reach or section of stream. Camp Creek has higher average elevation, lower stream water temperature, and better canopy cover than the mainstem of the Middle Fork. As a result, Camp Creek has a higher steelhead/rainbow trout density than the Middle Fork John Day. However, since the Middle Fork has a larger flow than Camp Creek, it contains more trout than Camp Creek per stream mile.

One major challenge of using data from a particular section of stream to analyze the relationships between fish abundance/stream temperature and hydrologic and riparian characteristics is to account for the impact of upstream conditions. The effects of upstream disturbances accrue downstream, and location of canopy can be as important as the longitudinal extent of canopy (Li et al.). To address this issue, the data were collected at focal reaches, which are located near the lower margins of shaded and unshaded "patches" of streams. For a detailed description of the data and the data collection process, see Li et al. and Adams et al. A full discussion of our empirical model and results appears in the American Journal of Agricultural Economics 82(May 2000):400-413.

The Importance of Cumulative Effects

This section utilizes our estimated results to explore the importance of cumulative effects in establishing vegetated riparian corridors, the main habitat investment alternative under Oregon's CREP and EQIP plans. We compare the effects of two targeting strategies on stream temperature and steelhead abundance. In the first scenario, we assume that conservation efforts are targeted toward stream reaches with the worst stream bank conditions (i.e, sections of Camp Creek and the Middle Fork with the lowest ratings on vegetation stability). In this scenario, by allocating funds according to a specific on-site characteristic, the cumulative effect of conservation efforts on steelhead abundance is ignored. In the second scenario, we assume that conservation efforts are targeted to maximize total steelhead numbers.[2]

The establishment of stream fencing and vegetated riparian corridors will reduce vegetation use and increase vegetative stability. In the long run, it will also increase canopy cover of streams. These improvements would reduce stream temperature and increase steelhead abundance. Using the estimated recruitment and temperature models, we simulate the effect of improvements in riparian conditions on juvenile steelhead abundance. Both fencing and vegetative cover are effective in increasing the ratings of vegetation stability and soil alteration. We assume that the vegetation stability rating and the soil alteration rating improve simultaneously in simulating the effect of riparian enhancements on stream temperature and juvenile steelhead abundance. Under this assumption, we derive the relationship between stream temperature and overall stream bank conditions as measured by stream bank vegetation stability. These relationships are then substituted into the recruitment model to determine the impact of stream bank conditions on juvenile steelhead abundance. The number of juvenile steelhead per stream mile is estimated by multiplying the density (#/m^3) by the volume of water per stream mile.

The impacts of stream bank conditions on stream temperature, juvenile steelhead density, and the number of steelhead per stream mile are shown in table 2. The estimates of stream temperature are a linear function of all coefficients in the temperature equation, and the estimates of steelhead density are a non-linear function of all coefficients in both the temperature model and the recruitment model. Because these estimates are calculated with regression coefficients that are point estimates, it is important to provide some indication of their precision. Thus, we computed t-statistic of these estimates using the Times Series Processor's ANALYZ procedure (Hall, pp. 26-27). The ANALYZ procedure provides estimates of t-statistics and standard errors for any function of estimated regression coefficients.

The results shown in table 2 can be used to explore the efficiency of habitat investments within a given stream, as well as across streams. Results suggest that when the objective is to increase juvenile steelhead abundance, conservation efforts should not be targeted toward stream reaches with a vegetation stability rating of two or higher in Camp Creek or a vegetation stability rating of three or higher in the Middle Fork because the marginal benefits are minimal (see Figure 3). When it is equally costly to increase the vegetation stability rating from two to three as to increase from one to two, the optimal targeting criterion of conservation efforts should be as follows. First, funds should be targeted at reaches of the Middle Fork with a vegetation stability rating of two, with an objective of increasing their vegetation stability to three. This will increase the number of juvenile steelhead by 1150 per stream mile. Second, funds should be targeted to reaches of the Middle Fork with a vegetation stability rating of one, with an objective of increasing their vegetation stability to three. This will increase the number of juvenile steelhead by 1596 per stream mile (the average increase is 798 for each improvement in ratings class). Finally, those reaches of Camp Creek with a vegetation stability rating of one should be targeted, with the objective of improving the rating to two. The marginal benefit of this improvement would be 399 juvenile steelhead per stream mile.

Because of the threshold effect of stream temperature on juvenile steelhead abundance, sections of the Middle Fork with a vegetation stability rating of two should be restored first rather than sections with a rating of one. Figure 2 shows that stream temperature reaches a threshold at about 19 ^0C in the Middle Fork. Until the stream temperature is reduced below 19 ^0C, conservation efforts have little effect on juvenile steelhead abundance. After the threshold is reached, further reduction in stream temperature would significantly increase juvenile steelhead abundance. For example, when the stream bank vegetation stability is increased from one to two, stream temperature would be reduced from 21 ^0C to 19 ^0C. This effort would only increase juvenile steelhead density from zero to 0.09 fish/m^3, or 446 juvenile steelhead per stream mile (see table 4). A further improvement in stream bank conditions from a rating of two to three would reduce stream temperature below the threshold (to 18 ^0C) and significantly increase juvenile steelhead abundance (to 0.32 juvenile steelhead/m^3 or 1150 juvenile steelhead per stream mile). Thus, ignoring the threshold effect and targeting reaches with the worst stream bank conditions instead of reaches with a rating of two would create an opportunity cost of 0.23 juvenile steelhead/m^3 or 704 juvenile steelhead per stream mile.

When conservation efforts are targeted toward stream reaches with the worst stream bank conditions, the reaches of Camp Creek with a vegetation stability rating of one would have a higher priority for funding than reaches of the Middle Fork with a vegetation stability rating of two. A budget constraint may create a situation where funds that should have been targeted toward reaches of the Middle Fork with a vegetation stability rating of two are targeted to reaches of Camp Creek with a vegetation stability rating of one. This misallocation would create an opportunity cost of 751 juvenile steelhead per stream mile of treatment if the restoration costs per stream mile are identical in the two streams.[3] Again, the opportunity cost arises from ignoring the threshold effect of stream temperature on juvenile steelhead abundance in the Middle Fork.

It may be more costly to increase vegetation stability from a rating of two to three than from one to two. For example, to increase vegetation stability from a rating of one to two may require only minor changes in cattle grazing management, whereas an increase from two to three may require fencing. As long as the cost of increasing vegetation stability from two to three in the Middle Fork is less than 2.58 times of the cost of increasing vegetation stability from one to two, the optimal targeting strategy specified above still applies.[4] In this case, the additional benefits of targeting reaches with a vegetation stability rating of two is still greater than the additional costs compared with targeting reaches with a vegetation stability of one. When the cost of increasing vegetation stability from two to three in the Middle Fork is between 2.58 and 2.88 times the cost of increasing vegetation stability from one to two, reaches of the Middle Fork with a vegetation stability rating of one should be targeted first, followed by reaches of the Middle Fork with a vegetation stability rating of two. When the cost of increasing vegetation stability from two to three in the Middle Fork is greater than 2.88 times the cost of increasing vegetation stability from one to two, reaches with a vegetation stability rating of one in both streams should be treated first.

This analysis implicitly assumes that the vegetation stability rating can be increased discretely. It is also possible that a conservation practice, when it is implemented, will increase vegetation stability from one to four. This may be the case for forested buffer strips, which, once established, would reduce vegetation use and increase vegetation stability. In this case, conservation efforts should first be targeted toward reaches of the Middle Fork with a vegetation stability rating of one, followed by reaches of Middle Fork with a vegetation stability rating of two. A switch of targeting order would create an opportunity cost of 446 juvenile steelhead for each untreated stream mile of the Middle Fork with a vegetation stability rating of one (Table 4). The opportunity cost of targeting a wrong stream when cumulative effects exist is even larger than misallocations within a stream. Targeting reaches of Camp Creek with a vegetation stability rating of one instead of reaches of the Middle Fork with the same rating would create an opportunity cost of 1148 juvenile steelhead per stream mile of treatment (Table 4).

Concluding Remarks

Federal and state conservation programs expend substantial resources to achieve a range of environmental objectives. Most programs are targeted to a specific objective, although targeted programs often lead to unintended negative outcomes, such as exacerbating other environmental problems. In addition, there are other problems associated with the way that such programs are targeted, including the occurrence of cumulative effects in investments to improve environmental quality. These effects are particularly pronounced in dealing with fish and wildlife habitat investments and have implications for the way funds are allocated to achieve objectives within different geographical settings. These effects have not been well investigated.

This paper has explored the consequences of cumulative effects in the context of an important habitat management issue in the Pacific Northwest, preserving wild stocks of steelhead trout. The analysis confirms the presence of cumulative effects in habitat investments within a case study watershed, the John Day River basin. These effects have important implications in terms of efficient allocation of management funds. This analysis indicates that allocation of funds according to typical allocation rules or guidelines will not be efficient in the presence of these cumulative 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. While a lack of natural science data in some settings makes efficient management difficult, the existence of cumulative effects seems plausible in most fishery or wildlife situations. This suggests that formulas or guidelines based on equity in distribution of funds across political or natural geographical boundaries, or keyed to a specific on-site environmental characteristic, are likely to result in both technical and economic inefficiencies.

Endnotes

* A longer version of this paper appeared in the American Journal of Agricultural Economics 82 (May 2000):400-413. The American Agricultural Economics Association is copyright holder of this material.

1. Numerous reasons have been cited for declining fish populations, including destruction of freshwater habitat, water quality, over harvesting, dams and disruption of fish migration, widespread drought episodes, unfavorable ocean survival conditions, and El Nino events.
2. Benefits are measured in terms of the changed number of steelhead, rather than an economic value of these changes, to be consistent with the mandates of the Endangered Species Act and the CREP and EQIP programs. When the objective of conservation programs is to maximize economic value rather than to protect an endangered species, the optimal allocation of habitat enhancement funds may differ from what is characterized in this paper.
3. In the Middle Fork, an improvement in vegetation stability rating from two to three would increase the number of juvenile steelhead by 1150 per stream mile, and in Camp Creek, an improvement in vegetation stability rating from one to two would increase the number of juvenile steelhead by 399 per stream mile (see Table 2). Thus, the opportunity cost

of the wrong targeting is 1150 – 399 = 751 juvenile steelhead per stream mile.

4. An improvement in vegetation stability rating from one to two would only increase the number of juvenile steelhead by 446 per stream mile in the Middle Fork and 399 in Camp Creek, compared with 1150 when the vegetation stability is increased from two to three in the Middle Fork. The ratios of the benefits are 1150/446 = 2.58 and 1150/399 = 2.88.

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Table 1. Summary Statistics of Selected Variables

Variable	Camp Creek			Middle Fork		
	Mean	Min	Max	Mean	Min	Max
Juvenile Rainbow Trout (Number/m^3)	1.45	0	5.73	0.42	0	4.16
Max. Summer Stream Temp. (^oC)	14	11	24	18	9	28
Bank Vegetation Stability (index)	2.70	1	4	3.33	1	4
Stream Bank Soil Alteration (index)	3.17	1	5	3.44	1	5
Water Surface Canopy Cover (%)	30.27	0	100	0.53	0	6.5
Elevation (*m*)	1416	1323	1448	1111	3	1289
Discharge (m^3/s)	0.05	0.03	0.23	0.59	0.17	1.91
Mean Stream Depth (*m*)	0.20	0.08	0.4	0.37	0.17	0.88
Mean Stream Width (*m*)	3.09	1.4	8.4	8.18	2.8	18.95
Bank Full Width (*m*)	6.15	2.5	12.5	15.33	6.93	30.8
Substrate	-3.26	-6.44	0.92	-3.86	-11.87	-0.1
Solar Heat Input (Megajoules/m^2)	1419	333	2200	1982	1568	2190
Velocity (m/s)	9.18	0.33	26.34	18.37	3.6	48.2
Embeddedness (index)	1.92	1.00	3.67	3.14	1	5
Gradient (%)	1.27	-8	4.5	0.69	0	2
Large Wood Debris (Piece)	0.18	0	2	0.03	0	1
Water Volume (m^3)	5	0	19	56	0	480
Water Surface Area (m^2)	25	5	66	169	17	809
Number of Observations	28			36		

Table 2. The Impact of Stream Bank Improvements on Water Temperature and Juvenile Rainbow Trout Abundance

	Water Temperature (^oC)		Trout Abundance (number /m^3)		Trout Per Stream Mile (number /mile)	
Stream Bank Condition	Camp Creek[a]	Middle Fork	Camp Creek	Middle Fork	Camp Creek	Middle Fork
1	17**	21**	0.98*	0.00	1006*	0
	(23.03)	(24.86)	(2.40)	(0.94)	(2.40)	(0.94)
2	15**	19**	1.36**	0.09	1405**	446
	(21.54)	(17.45)	(4.52)	(1.11)	(4.52)	(1.11)
3	14**	18**	1.41**	0.32	1454**	1596
	(21.22)	(17.80)	(5.11)	(1.87)	(5.11)	(1.87)
4	14**	18**	1.41**	0.32	1454**	1596
	(25.40)	(41.65)	(3.93)	(1.33)	(3.93)	(1.33)

[a] t-statistics are in parentheses; one and two asterisks indicate statistical significance at the 5% and 1% level, respectively.

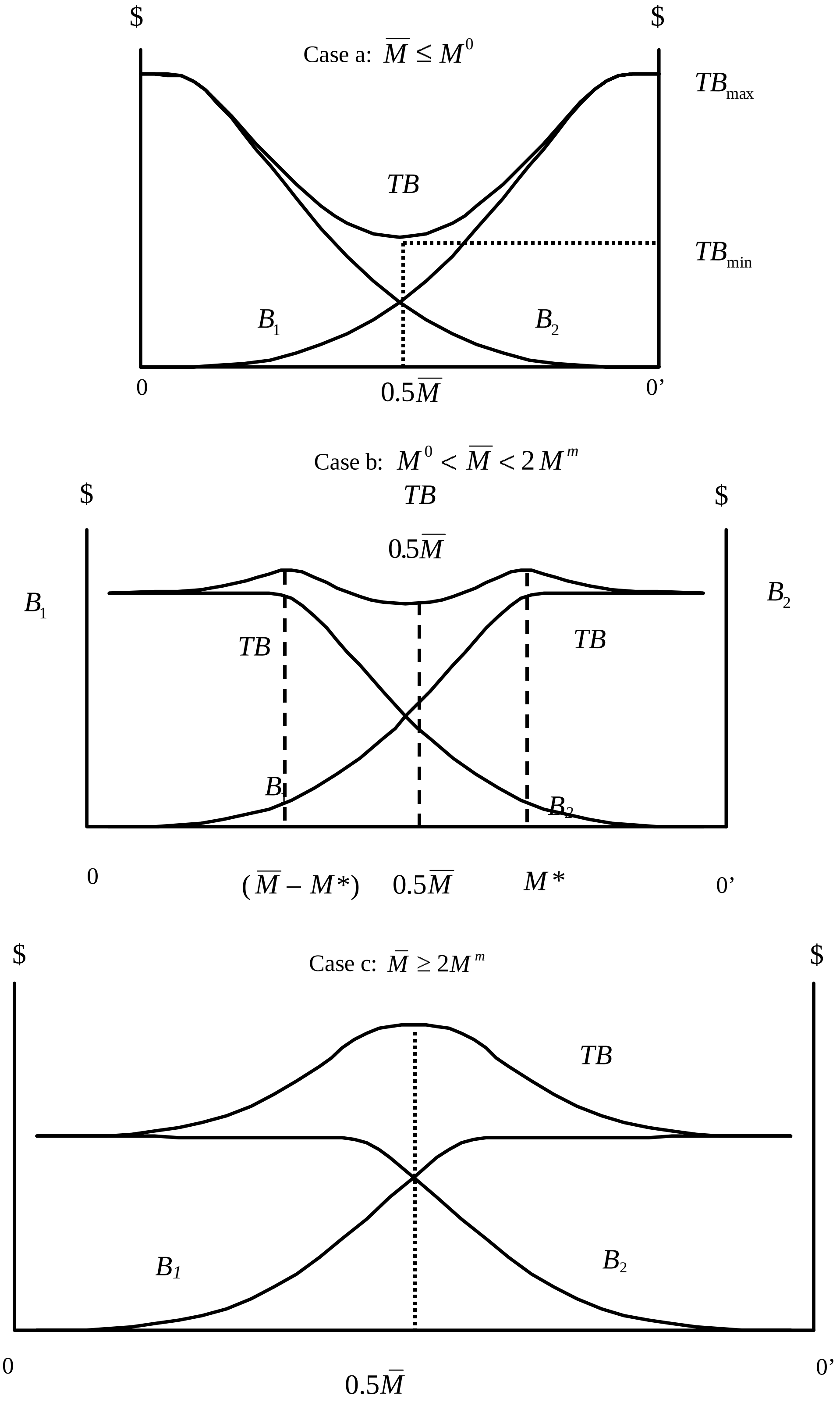

Figure 1. Fund Allocation between Two Identical Watersheds

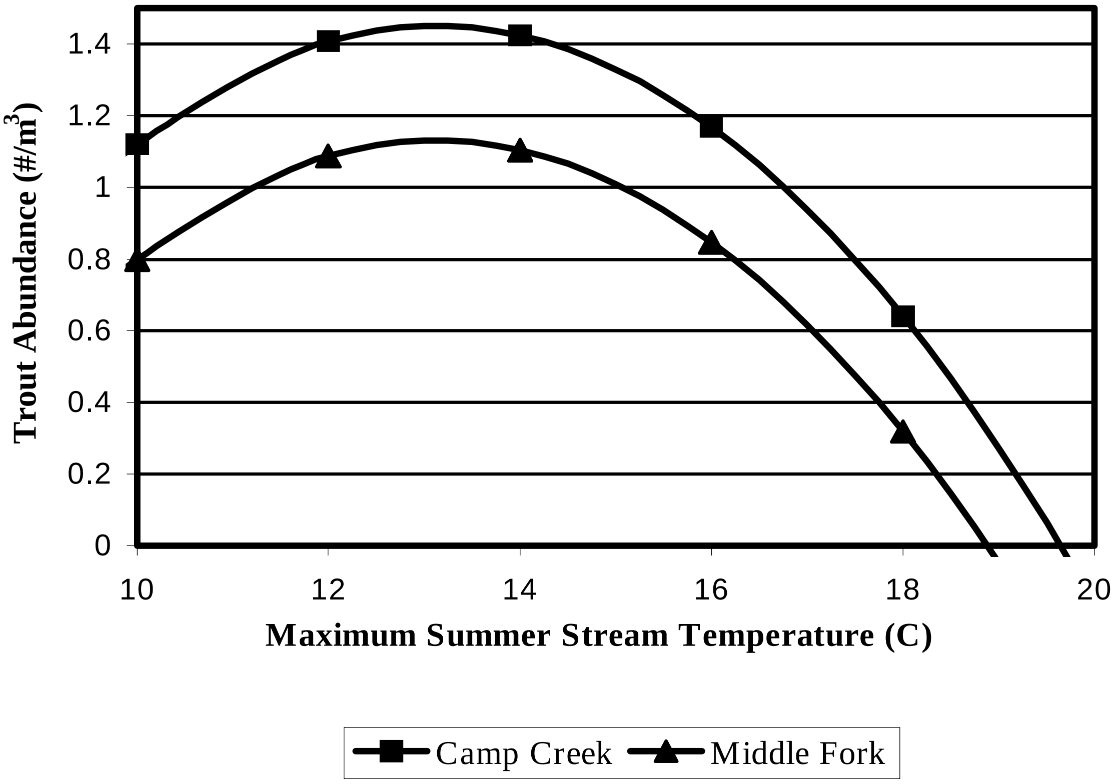

Figure 2. The Impact of Stream Temperature on Juvenile Rainbow Trout Abundance

Figure 3. The Impact of Stream Bank Vegetation Stability on Juvenile Rainbow Trout Abundance