Spatial Habitat Design by Agglomeration Bonus*

Gregory M. Parkhurst
Jason F. Shogren

Department of Economics and Finance
University of Wyoming
Laramie, WY 82071-3965

12 June 2003

Abstract

Herein we explore the robustness of the agglomeration bonus mechanisms designed to create voluntary spatial habitat configurations for protecting nature on private lands (e.g., endangered species, biodiversity). We design a grid game experiment to test whether the agglomeration bonus mechanism can induce four players to voluntarily coordinate their land retirement decisions to create four alternative biological habitats—a core, a corridor, a cross, and four corners. Our results suggest the agglomeration bonus can work. The bonus mechanism was most successful in achieving the corridor objective. Coordination to the core and cross was more difficult because it required all four players to align their actions. Voluntarily creating isolated corners was relatively easy. If players first had incentive to create these corners, coordination failure in the core was then more likely. Initial isolation incentives made it more difficult to induce players to coordinate at the core even when it was more profitable.

*Thanks to the Institute for Environment and Natural Resources, the Bugas funds, and Stroock professorship at the University of Wyoming for the financial support. Thanks to Tom Crocker, Stephan Kroll, John Tschirhart, and seminar participants at Washington, CIRANO, ERS/USDA, and Chico for their useful suggestions. All errors remain our own.

1. Introduction

About half of the species listed as threatened or endangered under the Endangered Species Act of 1973 (ESA) have about 80 percent of their critical habitat on non-federal lands, with nearly 20 percent of the species found entirely on private lands (see Innes et al., 1998; Brown and Shogren, 1998). Many experts believe that on-going pressure to develop private lands will continue to fragment critical habitat into ecologically precarious niches. Landowners are also concerned—they fear new ESA restrictions will put them in economically perilous circumstances. Pragmatists on both sides of the ESA debate are looking for new incentive mechanisms that could be used to address both economic and biological efficiency (e.g., Bean, 1999; Wilcove et al., 1996). Economic efficiency would compensate landowners who voluntarily retire acres to minimize their cost of species protection. Biological efficiency would compel landowners to retire acres to create the contiguous habitat across private property (see Sheldon, 1998).

One proposed voluntary incentive mechanism that addresses both concerns is the *agglomeration bonus* (see Smith and Shogren, 2001, 2002; Parkhurst et al., 2002). The agglomeration bonus reduces the landowners' costs of species protection and provides reason for them to coordinate land retirement decisions to create biologically desired contiguous habitat reserves. The agglomeration bonus works as follows. A regulator offers each landowner (i) a schedule specifying a monetary transfer for retired acres, and (ii) an agglomeration bonus to induce coordinated acre retirement to create one large habitat preserve across common borders.[1] The bonus pays the landowner for each border shared by two conserved acres, regardless if the border is solely on his own land or on

[1] Alternatively, if the goal is to create several small habitat preserves, the bonus can be constructed to repel conserved acres away from the common borders.

both his and his neighbor's land. Each landowner is being rewarded for the *shared border*, not the specific parcel. In effect, the agglomeration bonus creates a network externality between the landowners. Each landowner's conservation payment depends on their own voluntarily conserved acres, the conserved acres of their neighboring landowners, and the location of the conserved acres within the landscape.

The downside with the agglomeration bonus is that it creates a classic spatial coordination game (see Schelling, 1960; Cooper, 1999; Alpern and Reyniers, 2002).[2] A coordination game exists because the numerous combinations of conservation strategies and resultant payoffs create multiple Pareto-ranked Nash equilibria. The landowners now have to coordinate their conservation and production choices to achieve the maximum joint payoffs and first best habitat configuration. Each landowner must choose between a risky strategy that might maximize payoffs (i.e., payoff dominant strategy) and safer strategies that earns fewer profits with certainty (risk dominant strategy).[3] The failure to coordinate reduces economic gains and increases habitat fragmentation. Agglomeration bonus-coordination failure is more likely the more complex the desired spatial configuration of habitat—creating one contiguous habitat reserve across four landowners might be more challenging than creating four separate habitats.

This paper uses experimental methods to testbed the agglomeration bonus for spatial habitat design. Using a spatial *grid game*, we explore whether the bonus can induce four landowners to create four distinct spatial conservation habitat objectives—a

[2] Coordination problems have received much attention in the experimental economics literature (see e.g., Cooper et al., 1990, 1992; Berninghaus and Ehrhart, 1998; Van Hyuck et al., 1990, 1991; Ochs, 1995).
[3] See Harsanyi and Selten (1988).

corridor, a core, a cross, and four isolated corners.[4] Figure 1a illustrates our four-player 10x10 grid game. Each player owns 25 land parcels plotted on a 5x5 grid, in which all parcels have a pre-assigned market value ($2, 4, 6, 8, or 10) that is common knowledge. He can decide to conserve up to 5-6 parcels based on the conservation objective. When choosing to retire parcels, a player has over 68,000 possible strategy choices within the grid that creates over $(68K)^4$ total potential payoff outcomes, with numerous Pareto-ranked Nash equilibria, only one of which is the Pareto dominant outcome.[5] Players also have imperfect information about how all strategy sets translate into potential payoffs.

Within this complex environment, our results suggest the agglomeration bonus can work to create the desired spatial habitat. The bonus was most effective at creating a contiguous corridor. Coordination to a core or cross design was more challenging because this required all four players to bring together their actions. The results also show that voluntarily creating the four isolated corners was relatively straightforward. If players initially created these corners, however, coordination failure for the core and corridor designs was more likely. Initial isolation incentives made it more difficult for the agglomeration bonus to induce players to coordinate to the more profitable core.

2. Habitat Fragmentation and Spatial Configurations

Consider now the four spatial habitat configurations we consider in our grid game experiment. Conservation biology says many species face extinction due to fragmented

[4] In a pilot test on the corridor, Parkhurst et al. (2002) considered a standard two-player context-free, normal form coordination game with multiple Pareto ranked Nash equilibria, with and without cheap talk. Normal form designs capture the theoretical assumption that players are rational with common knowledge on their own and the other player's payoffs associated with all actions. The normal form game compresses land configurations and habitat retirement decisions into single actions, which is the best game structure to generate behavior supportive of the agglomeration bonus.
[5] The number of Nash equilibria depends on the structure of the agglomeration bonus. In some cases more than 9000 Nash equilibria exist.

habitat on both public and private lands. Habitat fragments are either too small to provide species with the physical and biological landscape characteristics necessarily for survival and breeding, or they are too isolated from other fragments causing species "bottlenecks", which increases susceptibility to changes in its environment (e.g., Saunders et al., 1991; Willis, 1984; Gilpin and Diamond, 1980; Whitcomb et al., 1976; Higgs and Usher, 1980).[6] But biology also points out that *how* one reconfigured fragmented habitat matters because different species thrive under different spatial habitat designs (Noss, 1993; Diamond, 1976; Terborgh, 1976). We use the agglomeration bonus to voluntarily create four different spatial conservation objectives—a core, a corridor, a cross, and a corner habitat configuration.[7]

First, some species thrive within one large habitat *core* (e.g., northern spotted owl, red-cockaded woodpecker, grizzly bears). Figure 2a illustrates the habitat core we consider within our 10x10 grid game. A large core minimizes *edge effects*. Edge effects occur at the boundary between conserved and productive parcels, and increases the risks to species. Species are driven further into the habitat core to escape the risks posed by nest paratism and the penetration of light and wind into the habitat, which reduces total area and lowers the population persistence (see Vickery et al., 1994; NRC, 1993). Given limited conservation dollars, designing habitat reserves to minimize edge effects along a *core* area increases the odds of survival.

---

[6] "Bottlenecks" emerges from inbreeding and refers to reduced chromosomes types in a species' DNA.

[7] Specific guidelines have been proposed to design habitat preserves for land sensitive species: The distribution of a species should be across its entire range; larger habitat preserves are preferred to smaller habitat preserves; the smaller the distance between preserves the better; coordinating conservation to create one large habitat preserve is preferred to numerous smaller fragmented preserves; two habitat fragments should be linked with a conservation corridor of like habitat; and habitat blocks that are protected from human interaction are preferred (see Noss, 1993).

Second, most species benefit from access to a long habitat *corridor* (see Figure 2b) that allows movement from reserve to reserve (e.g., wolves, salmon). Some areas have two large reserves, and creating a habitat corridor that connects these reserves may be the best conservation strategy. The conservation corridor allows immigration between large habitat parcels, increasing the species probability of survival by reducing the likelihood of a "bottleneck" (Noss, 1993). Species are then exposed to numerous populations and therefore a more diverse gene pool (NRC, 1993; Saunders et al, 1991).

Third, experts believe that the best strategy for some species is to design a lengthy corridor with a habitat *cross* or rest area (see Figure 2c) along the path which facilitates both residence along the path and migration between larger habitat parcels (e.g., grizzly bear). The *cross* habitat configuration is most helpful the longer the distance between core populations. Adding a cross to a corridor can lower rates of natural and anthropogenic risks in what have been called '*genetic sinks*', e.g. exposure to edge-inhabiting predators, diseases carried by domestic animals, and poaching, which increase the longer the corridor (McKenzie, 2003). Stepping stone habitat patches, either unconnected or connected by shorter habitat corridors, is one way to protect species (Simberloff et al., 1992). A good example is the grizzly bear in the Rocky Mountains. The grizzly has large land requirements and the distance between core populations is extensive. They are able to reside along the corridor, which benefits the species by allowing migration between core populations and emigration from the corridor to the larger habitat parcels (Beier and Noss, 1998).

Fourth, those species susceptible to diseases are better managed as meta-populations in isolated conservation *corners* (e.g., bison, prairie dogs, black-footed ferrets). Figure 2d illustrates the four corner target. Species susceptible to diseases should be managed as meta-populations with isolated habitat areas that meet a minimum population size or core area, e.g., black-footed ferret or the black-tailed prairie dog populations affected by the plague. Interaction of distinct species populations here is not necessarily beneficial. Corridors should be avoided if they provide an avenue to spread disease between populations (Saunders et al., 1991; BFFRIT, 2002).

3. Designing the Agglomeration Bonus

We design the agglomeration bonus to create incentives to achieve these four habitat designs on private lands—the corridor, core, cross, and four corners. Following Hof and Bevers (1998), we use a cellular model to capture the importance of the spatial configuration of the retired habitat acres. The cellular model separates the landscape into cells of equal size and assigns each cell a number according to its placement in the landscape. We consider privately owned landscape separated into four individual landholdings of equal size. Land is further divided into measurable parcels of equal size define in square miles, acres, hectares, or another acceptable measurement. Figure 1b shows the private landholdings. Each landowner owns a 5x5 area of land, or 25 parcels. Productive value is parcel-specific. Each parcel is identified by its longitudinal and latitudinal placement in the landscape.

Each landowner uses his land parcels to produce a marketable commodity, *y*, i.e., the numeraire good sold at an exogenous market price. The value of production is heterogeneous and parcel specific. Land parcels not used for producing *y* are preserved as habitat and provide no market gain to the landowner.[8] Assume landowners are profit maximizers and all conservation is voluntary. For simplicity, assume landowners assign no non-market values to habitat, and no secondary private market exists for habitat or other environmental amenities.[9]

Assume a regulatory agency (e.g., Wyoming Game and Fish) identifies both the land desired for conservation and the habitat configuration (e.g., core or corner). They then design an agglomeration bonus mechanism to create incentives to persuade each landowner to conserve the parcels that achieves the conservation objective.[10] Our agglomeration bonus is a subsidy menu mechanism with four specific subsidies: (1) a *per conserved habitat acre subsidy*, S_H; (2) an *own shared border subsidy*, S_{OB}, which pays the landowner a subsidy for every border that is shared between two of his own conserved acres (see Figure 3a); (3) a *row shared border subsidy*, S_{RB}, which pays a landowner a subsidy for every border shared by one of his habitat acres and a habitat acre of the row neighboring landowner (Figure 3b); and (4) a *column shared border subsidy*, S_{CB}, which pays the landowner a subsidy for every border shared by one of his habitat acres and a habitat acre of the column neighboring landowner (Figure 3c). The value of

---

[8] A secondary market could exist in which the landowner sells the right to hunt or camp or otherwise experience his conserved habitat. Herein we assume a secondary wilderness market does not exist.

[9] The value h_{Ti} ($T = U, R, C, A$; $i = (1, 1),\ldots, (10, 10)$) is confined to the payment the landowner can receive from the government regulator.

[10] This mechanism has individual subsidies to be paid to landowners on a per conserved acre basis, can be attached to a common border between two conserved parcels either within or across landowner holdings so that landowners can receive an additional payment when two conserved acres share a common border. The agglomeration bonus can also be attached to the border of a land characteristic such as national forest land or a river or other land attribute so that landowners receive an additional payment when their conserved land borders a desired land attribute such as a river. The value of the various subsidies can differ and the magnitude of each subsidy will depend on the productive value of the land. Although the values of the various subsidies can differ across subsidy type, the subsidy value does not differ across landowners. For example, if the per acre subsidy is set at $10, then every parcel set aside for habitat by every landowner would earn the same $10 per conserved parcel subsidy.

these subsidies can be positive, negative, or zero, and depend on productive values and desired configuration and location of the habitat.

The subsidy menu serves two purposes—to make conservation profitable, and to create a network externality between landowners' conservation decisions. The cross, core, and corridor conservation objectives create a network externality between landowners' conservation patches in which landowners act as if they were cooperating by locating their retired parcels on common borders to earn maximum profits. The corner conservation objective imposes a negative subsidy (tax) on two landowners who share a common conservation border. Now one landowner's conserved habitat depends on his own conservation and on the conservation decisions of his neighboring landowners.

The coordination game emerges here because the grid game is a supermodular game. A supermodular game exists when one can order elements in the strategy space of the players and strategic complementarity exists between players' actions (see Milgrom and Roberts, 1990). Since the subsidy menu creates a network externality each landowner's conservation decisions complements the others. The landowner's profit maximization problem is therefore a coordination game with multiple Pareto ranked equilibria. The typical solution to a coordination game is a mixed strategy in which players choose the probability of playing each strategy based on their own payoffs and on the other players' payoffs. We allow for nonbinding communication or cheap talk to exist between players, as is likely to occur between landowners. In a coordination game, nonbinding cheap talk is argued to still be credible, because players have no incentive to deviate from their communicated strategy (Farrell, 1987).

Regulator's Problem

We now examine the problem facing the regulator and the landowner. The regulator's goal is to design the incentive mechanism to achieve the predetermined conservation objective. The regulator manipulates the four subsidies, S—S_H, S_{OB}, S_{RB}, and S_{CB}, to create the desired conservation objective. Intuitively, he designs the agglomeration bonus subsidy menu on a cell-by-cell basis. He imposes a series of linear constraints on each subsidy such that the opportunity cost of not conserving the targeted habitat exceeds the opportunity cost of any other possible habitat conservation strategy. The conditions we set forth for each of the agglomeration bonuses are sufficient to ensure the optimal habitat configuration is achieved. They are not necessary; lower subsidy values may achieve the desired objective in some cases.

For the core objective, for instance, each landowner should conserve a 3x2 conservation patch in the center of the grid. Figure 1b summarizes the general theoretical grid game we use to constrain the agglomeration bonus for the specific conservation target. Assuming the regulator is restricted to setting one value for all landowners for each of the four subsidies, the following five sets of sufficient conditions define the agglomeration bonus to create the core:

$$S_H > \min(y) \tag{1}$$

$$S_{RB} > \begin{bmatrix} \max(y_{(5,w)} - \min(y)) \\ \max(y_{(6,w)} - \min(y)) \\ 0 \end{bmatrix} \tag{2}$$

$$S_{OB} > \begin{bmatrix} y_{(4,5)} - \min(y_{(3,5)}, y_{(2,5)}, y_{(1,5)}) \\ y_{(7,5)} - \min(y_{(8,5)}, y_{(9,5)}, y_{(10,5)}) \\ y_{(7,6)} - \min(y_{(8,6)}, y_{(9,6)}, y_{(10,6)}) \\ y_{(4,6)} - \min(y_{(3,6)}, y_{(2,6)}, y_{(1,6)}) \\ S_{RB} + \frac{1}{2}(y_{(3,4)} + y_{(4,4)} - y_{(5,2)} - y_{(5,3)}) \\ S_{RB} - \frac{1}{2}(y_{(7,4)} + y_{(8,4)} - y_{(6,2)} - y_{(6,3)}) \\ S_{RB} - \frac{1}{2}(y_{(3,7)} + y_{(4,7)} - y_{(5,8)} - y_{(5,9)}) \\ S_{RB} - \frac{1}{2}(y_{(7,8)} + y_{(8,8)} - y_{(6,8)} - y_{(6,9)}) \\ 0 \end{bmatrix} \tag{3}$$

$$S_{CB} > \begin{bmatrix} y_{(4,5)} - \min(y_{(4,4)}, y_{(4,3)}, y_{(4,2)}, y_{(4,1)}) \\ y_{(4,6)} - \min(y_{(4,7)}, y_{(4,8)}, y_{(4,9)}, y_{(4,10)}) \\ y_{(7,5)} - \min(y_{(7,4)}, y_{(7,3)}, y_{(7,2)}, y_{(7,1)}) \\ y_{(7,6)} - \min(y_{(7,7)}, y_{(7,8)}, y_{(7,9)}, y_{(7,10)}) \\ S_{RB} - y_{(5,3)} - y_{(4,3)} + y_{(3,5)} + y_{(3,4)} \\ S_{RB} - y_{(6,3)} - y_{(7,3)} + y_{(8,5)} + y_{(8,4)} \\ S_{RB} - y_{(6,8)} - y_{(7,8)} + y_{(8,6)} + y_{(8,7)} \\ S_{RB} - y_{(5,8)} - y_{(4,8)} + y_{(3,6)} + y_{(3,7)} \\ 3S_{RB} - 2S_{OB} - y_{(5,1)} - y_{(5,2)} - y_{(5,3)} + y_{(3,5)} + y_{(4,4)} + y_{(3,4)} \\ 3S_{RB} - 2S_{OB} - y_{(6,1)} - y_{(6,2)} - y_{(6,3)} + y_{(8,5)} + y_{(7,4)} + y_{(8,4)} \\ 3S_{RB} - 2S_{OB} - y_{(5,8)} - y_{(5,9)} - y_{(5,10)} + y_{(3,6)} + y_{(4,7)} + y_{(3,7)} \\ 3S_{RB} - 2S_{OB} - y_{(6,8)} - y_{(6,9)} - y_{(6,10)} + y_{(8,6)} + y_{(7,7)} + y_{(8,7)} \end{bmatrix} \tag{4}$$

$$S_{CB} < \begin{bmatrix} S_{OB} + y_{(2,5)} - y_{(3,4)} \\ S_{OB} + y_{(2,6)} - y_{(3,7)} \\ S_{OB} + y_{(9,5)} - y_{(8,4)} \\ S_{OB} + y_{(9,6)} - y_{(8,7)} \\ S_{RB} + \frac{1}{2}(y_{(2,5)} + y_{(1,5)} - y_{(3,4)} - y_{(4,4)}) \\ S_{RB} - \frac{1}{2}(y_{(9,5)} + y_{(10,5)} - y_{(7,4)} - y_{(8,4)}) \\ S_{RB} - \frac{1}{2}(y_{(9,6)} + y_{(10,6)} - y_{(7,7)} - y_{(8,7)}) \\ S_{RB} - \frac{1}{2}(y_{(1,6)} + y_{(2,6)} - y_{(3,7)} - y_{(4,7)}) \end{bmatrix} \tag{5}$$

where w = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. See Appendix A for the exact details on the subsidy design for the corridor, cross, and corner configurations.

Landowner's Problem

The landowner maximizes profits by producing, *y*, and by conserving habitat and accumulating subsidy dollars. Assume landowners can communicate before any conservation or production decisions are made. Landowner U's profit equation is

$$\pi_U = \sum_{i=(1,1)}^{(N,N)} \phi_{Ui} y_{Ui} + S_H \sum_{i=(1,1)}^{(N,N)} h_{Ui} + S_{OB} \sum_{i=(1,1)}^{(N,N)} h_{Ui} \sum_{j=(1,1)}^{(N,N)} \delta_{ij} h_{Uj}$$
$$+ S_{RB} \sum_{i=(1,1)}^{(N,N)} h_{Ui} \sum_{j=(1,1)}^{(N,N)} \delta_{ij} h_{Rj} P_U(y,S,\alpha) + S_{CB} \sum_{i=(1,1)}^{(N,N)} h_{Ui} \sum_{j=(1,1)}^{(N,N)} \partial_{ij} h_{Cj} P_U(y,S,\alpha) \quad (6)$$

subject to

$$\sum_{i=(1,1)}^{(N,N)} \phi_{Ui} + \sum_{i=(1,1)}^{(N,N)} h_{Ui} = L_{Ui} \quad (7)$$

$$\sum_{i=(1,1)}^{(N,N)} h_{Ui} \le H_U \quad (8)$$

where ϕ_{Ui} equals 1 if landowner *U* produced the marketable commodity, *y*, on acre *i*; 0 otherwise. Let $P_U(h_{Tj} \mid y,S,\alpha)$ be the probability landowner *U* assigns to the odds that landowner *T* (*T = R, C, A*) sets aside acre *j* as habitat, h_{Tj}. The probability of conserving land is affected by the productive value of every acre in the landscape, *y*, the subsidy menu mechanism, *S*, and a pre-play, non-binding communication, α. If $\alpha = 1$, communication indicates landowner *T* sets aside acre *j* as habitat, landowner U's probability equals $P_U(h_{Tj} \mid y,S,\alpha) = 1$.[11] Alternatively, if $\alpha = 0$, landowner *T* indicates he plans to produce on acre *j*. Equation (7) says the landowner either produces *y* or conserves habitat, *h*. Equation (8) says a landowner can conserve at most H_U habitat acres, but is not required to conserve any. The landowner's decision to provide habitat is

[11] Because the agglomeration bonus creates a coordination game, subjects have no incentive to deviate from their communicated conservation strategy (Farrell, 1987, 1988).

completely voluntary. The regulator sets the values of the various subsidies within the bonus menu so landowners earn maximum payoffs when they coordinate to the dominant Nash equilibrium that jointly conserves the desired conservation objective.

4. Experimental Design

Our experimental design had ten structural elements—treatments, players/matching, the land grid, subsidies, strategies, calculator, communication, information, history, and procedures. Consider each in turn.

Treatments. Four conservation treatments were tested—the corridor, core, cross, and corner. In sessions 1-7, we used an ABA treatment design (e.g., core, corridor, core). In sessions 8-10, we used an AB treatment design.[12] These AB sessions were run in part to test whether initial experience with non-coordination on the fence line (i.e., the corner treatment) affected a group's ability to coordinate on the fence line (i.e., core or cross treatments). Each treatment had 10 rounds. In sessions 1-7, subjects participating played a total of 30 rounds (ABA: 10x3=30). In sessions 8-10, subjects participated in 20 rounds (AB: 10x2=20).

Number of players and random matching. Eight subjects participated in a session. They were told they would be randomly assigned to a group of four subjects, and at the end of each round the computer would randomly reassign them to a new group of four subjects. We chose random groupings for two reasons: (1) the regulator is likely to only have one-shot at creating the desired habitat. Land development is typically considered irreversible; and (2) experimental evidence in normal form coordination games with

[12] We omitted the last treatment in these sessions because we found that coordination to the four corners was trivial. When coordination failed it typically was a result of one person locating on the column border; only 6 percent failed to achieve the four isolated habitat reserves (see Table 2).

cheap talk communication indicates that randomly paired subjects coordinate to the dominant Nash equilibrium about 6 percent more often than do subjects in a repeated game (Parkhurst et al., 2002), which creates the best opportunity for coordination.

The land grid. After each subject sat at his or her own computer terminal, the screen revealed the 10x10 land grid (Figure 1). Each subject knew that they owned a 5x5 portion of the 10x10 grid, and identified himself or herself as the *U* participant. The computer matched subjects and transposed each subject's 5x5 grid within the 10x10 landscape to reflect their position in relation to the other subjects. Subjects are faced with an identical 5x5 grid of values for each treatment and each conservation objective. Subjects were told the other subjects in their group had identical payoff matrices and placement in the landscape is also identical; the subject is the row participant for his row participant and the column participant for his column participant. We assigned values to the 10x10 grid to testbed the agglomeration bonus. Each subject had 5 cells valued at \$2 in row 1, 5 cells valued at \$4 in row 2, 5 cells valued at \$6 in row 3, 5 cells valued at \$8 in row 4, and 5 cells valued at \$10 in row 5 along the common row border. The value in each cell represents the productive value of that cell.

Conservation-specific-subsidies and maximum number of retired acres. Table 1 shows the subsidy values for each conservation treatment and order of treatments in sessions. Subjects had a specification page that showed the subsidy values for each of the four individual subsidies and included the land values for the entire 10x10 grid.

Strategies—Brown out cells. Subjects were instructed that they could leave their cells *green*, in which case they earned the value in the cell, or they could *brown out* cells, which mean they earn the applicable subsidies but forego the value of the cell. The maximum number of cells the subjects were allowed to "brown out" was specified on the computer screen. For the cross, core, and corner conservation types subjects could brown out a maximum of 6 cells, and a maximum of 5 cells could be browned out for the corridor conservation objective. Subjects could leave all cells green if they preferred. Note the large set of potential strategy permutations. By presenting subjects with the land grid and allowing voluntary participation the subjects have tens of thousands of strategies to choose from. The number of strategy choices for the corridor treatment, for example, is 68,406.[13] And because there are 4 subjects in each group, the possible group outcomes for the corridor treatment are $(68{,}406)^4$.

Calculator. To aid the subjects in calculating profits a grid calculator was provided on the computer screen. The grid calculator was a 10x10 grid of cells with borders to differentiate each player's portion of the section. The subject's portion of the calculator was tied directly to his 5x5 grid and reflected the choices made on the 5x5 grid. This means that if a subject clicked on a cell in his grid, changing the color from green to brown, the same cell turned brown on the calculator. For the other players portions of the calculator the subject clicked the cells directly. The subject's own potential profits, based on the configuration of brown cells on the calculator, were calculated and displayed on the computer screen.

Communication. Subjects were also provided the opportunity to communicate one message per round. Communication was non-binding, unstructured with no restrictions on timing or content, and in which a common language was implemented by

[13] To calculate strategy choices a combination was used. N was an element of the set [0,5] and the number of cells to choose from was 25. The equation is (25!/5!20!) + (25!/4!21!) + (25!/3!22!) + (25!/2!23!) + (25!/1!24!) + (25!/0!25!) = 68,406.

allowing subjects to send messages in their natural language (Crawford, 1998). Subjects had two minutes to send messages, use the calculator, and send their choices.

Public and private information. After all four subject's choices were submitted, the resulting grid was presented to the group. The subjects' 5x5 grid of values, the maximum allowed number of brown cells, a message box, and the grid calculator came up on the computer screen and players chose the cells to brown out. Subjects had common knowledge regarding payoffs and strategies. Each subjects individual payoffs and accumulated payoffs were private information.

History. The entire 10x10 grid showing the configuration of brown cells and the payoffs for each subject within the group then appeared in the history box. Subjects were provided with record sheets, as well as the history box, to help him or her keep track of his own and the other group members' choice of strategies and associated payoffs in previous rounds. The process was repeated every ten rounds as subjects were handed a new bonus specification page designed to achieve a new conservation objective.

Procedures. All experiments were run on computers. Subjects were not told the objective of the experiment and all wording in the instructions and on the computer screens were context free. Following standard protocol, subjects were recruited campus wide and were told to report at a computer lab at a given time. Experimental instructions were provided to each of the participants and the monitor read them out loud while the subjects followed along. See Appendix B for the exact instructions. Subjects were given an opportunity to ask questions concerning the experimental procedures, which were answered by the monitor. The monitor also walked the subjects through two practice rounds to familiarize the subjects with the experimental design. The monitor handed out the agglomeration bonus specification page, which the subjects were allowed to review. The subjects then entered their name and student identification number into the computer, and the computer randomly assigned the subjects to groups of four.

5. Results

We present the results in two stages. First, we discuss the observed group outcomes, and then we evaluate the success of the agglomeration bonus by economic and biological efficiency for each conservation target. Consider now the observed outcomes.

We separate group outcomes into three classes—a first best habitat outcome, a second best habitat outcome, and a third best-fragmented outcome.[14] We use Figure 4 to help illustrate the general play in the grid game; the figure shows the behavior of a group of players over 30 rounds in a core-corridor-core session.[15] For the corridor and core, the first best outcome is the optimal conservation configuration; the second best outcome is coordination to a non-optimal but contiguous habitat reserve; and the third best is any combination of strategies that creates fragmented habitat.

In rounds 1-10, we introduced the agglomeration bonus to create the core habitat. In round 1, Figure 4 shows three players retired acres that connected habitat, while one player did not (in the northwest corner). Only the player in the southeast corner played the Pareto dominant strategy. The end result was fragmented habitat. In round 2, we see even more fragmentation. By round 4, the players created a contiguous second best

[14] For the corridor, core, and cross treatment, the first best outcome is the optimal conservation configuration; the second best outcome is coordination to a non-optimal contiguous habitat reserve; and the third best is any combination of strategies that result in fragmented habitat. For the corner treatment, the first best outcome is the optimal isolated habitat reserves; the second best outcome is any set of strategies that result in four isolated reserves that are non-optimal; and the third best outcome is coordination to more or less than four isolated habitat reserves.

[15] Recall there are two groups per session and the eight subjects are randomly reassigned each round, which means subjects may be in different positions within the landscape or may be assigned to the other group in subsequent rounds.

habitat—two choose the Pareto strategy, two did not. In round 7, three players found the Pareto dominant strategy. Finally, in round 10, all four players coordinated on the Pareto dominant strategy to conserve the core. It took ten rounds, but the agglomeration bonus finally induced this group to voluntarily create the biologically desired core.

In rounds 11-20, we introduced a new agglomeration bonus to meet a new goal of a corridor habitat. Figure 4 shows in the initial two rounds (11-12), the players created a second best contiguous habitat. But then in the next round (13), they coordinated to the first-best corridor, and stayed with it from then on. They learned more rapidly to coordinate. Finally, in rounds 21-30, we reintroduced the bonus to create the core again. Within one round, all four players coordinated to create the core and did not waver (rounds 22-30). Figure 4 is an illustrative example on how the agglomeration bonus can work to induce one grouping of people to create voluntarily the desired conservation target. We now examine our overall findings in more detail.

Table 2 summarizes the group outcomes for each conservation objectives over all rounds for experienced and inexperienced subjects.[16] We consider each target in turn. *Corridor*. The corridor along the common row border was conserved in 70 percent of all rounds. Subjects in rounds 11-20 achieved the optimal habitat corridor 73 percent in rounds and achieved the second best contiguous habitat outcome in 18 percent. Subjects in rounds 21-30 coordinated to the conservation objective in 100 percent. Regarding how experience affects behavior, we see most cases of fragmentation can be attributed to inexperienced groups in rounds 1-10. Experienced groups created fragmented habitat only 5% of the time. *Core*. For all observations, we see 36% optimal core, 18% second

[16] By saying the subject is experience we mean the subject has at least 10 rounds of experience with the computerized experimental program.

best conterminous habitat reserves, and 45% fragmented habitat. For inexperienced subjects (rounds 1-10), we observe 31% optimal core, 21% second best, and 48% fragmentation. For subjects in rounds 21-30 with experience in the core objective (in rounds 1-10), we see 76% optimal core, 5% second best, and 19% fragmentation. In rounds 11-20 the outcomes were dismal—only 1% optimal core, 29% second best, and 70% fragmentation. For rounds 11-20, the group's initial experience mattered. When subjects had experience with habitat objectives that require coordination (e.g., the corridor), they achieve the first or second best continuous habitat 53% of the time; if they first experienced the isolated corner objective, they achieved first and second best outcomes only 10% of the time.

Cross. All observations here are for subjects experienced with the four corners treatment but inexperienced with cross conservation objective. From Table 2 we see 30% optimal cross, 43% second best, and 28% fragmentation. *Corner*. For inexperienced subjects, we see 45% optimal corners, 44% four non-optimal isolated reserves, and 11% more-or-less-than four habitat reserves. For subjects experienced with a treatment but inexperienced in the corners objective, we observe 75% optimal configuration, 25% second best, and 0% more-or-less-than four reserves. For subjects experienced in achieving the corner conservation objective, group outcomes were equally split between the optimal four corners and the second best non-optimal four isolated habitat reserves.[17]

We state our first key result based on the group outcomes.

---

[17] The majority of experienced play that resulted in a second best outcome was from one player who located his habitat reserve on the common border; because the other player did not locate on the common border the player earned the same payoffs as the other players. The player locating on the common border played a dominated strategy—if the other player had located on the same border earnings would decrease, and the conservation reserve is considered non-optimal.

Result 1: *(a) At the group level, the agglomeration bonus was the most successful in achieving the first best outcome for the corridor conservation objective. This held for experienced play (rounds 11-30). For inexperienced play, subjects were best at achieving the four corners conservation objective. (b) As expected, when the complexity of the coordination problem increases in the sense that all four players must coordinate to maximize payoffs (e.g., core and cross treatments), coordination failure increases. (c) Relative to those groups that initially play the corridor treatment (rounds 1-10), groups who initially play the isolated corner treatment had more difficulty coordinating in the core treatment in later rounds.*

Support. For *Result 1a* we test the null hypothesis: the probability of achieving the corridor is less than the probability of achieving the core and four corners conservation objectives in rounds 11-30. Using a Chi-square probability test, we reject the null hypothesis at the 5% significance level for both the core and four corners conservation objectives ($P_{core,11\text{-}30} \geq P_{corridor,11\text{-}30}$, $T_1 = -6.22$, p-value < 0.001; $P_{corner,11\text{-}30} \geq P_{corridor,11\text{-}30}$, $T_1 = -1.97$, p-value = 0.024).[18] We next test if the probability of achieving the four corners in rounds 1-10 is less than the probability of achieving the other conservation objectives. Again, for both the corridor and the core, we reject the null hypothesis at the 5% significance level (H_o: $P_{core,1\text{-}10} \geq P_{corner,1\text{-}10}$, $T_1 = -1.95$, p-value = 0.026; H_o: $P_{corridor,1\text{-}10} \geq P_{corner,1\text{-}10}$, $T_1 = -0.91$, p-value = 0.181). For *Result 1b* the null hypothesis is the probability of coordination is greater than or equal for the core and cross treatments relative to the corridor treatment. We reject the null hypothesis at the 1% significance level for rounds 11-30 (H_o: $P_{core,11\text{-}30} \geq P_{corridor,11\text{-}30}$, $T_1 = -6.22$, p-value < 0.001; H_o: $P_{cross,11\text{-}20} \geq P_{corridor,11\text{-}20}$, $T_1 = -2.46$, p-value = 0.007). In rounds 1-10, we cannot reject the null hypothesis (H_o: $P_{core,1\text{-}10} \geq P_{corridor,1\text{-}10}$, $T_1 = -0.68$, p-value = 0.249).

Turning now to *Result 1c*, we test the null hypothesis that the form of coordination failure—second-best or fragmented—is invariant to experience type. We

[18] The Chi-square probability test follows the standard normal distribution (Conover, 1999). Appendix D provides the data for the statistical tests.

reject the null hypothesis at the 1% significance level (Here we test the probability of coordination failure resulting in 2nd best outcomes—H_o: $P_{corner,core} \geq P_{corridor,core}$ T_1 = -3.282, p-value < 0.001). Subjects with initial experience achieving cooperating objectives tend toward second-best coordination failures; whereas subjects who first play isolated corner strategies are more likely to continue to play these isolated strategies even when the underlying incentives require cooperation to earn maximum payoffs. The form of coordination failure appears to be path dependent; as the subjects' common experience seems to create sticky focal points (see Schelling, 1960, p. 54-58). The corners seem to act as a focal point for some subjects even though the new incentives should lead them to create a contiguous habitat (e.g., core, corridor).

We now evaluate the success of the agglomeration bonus by economic and biological efficiency for each conservation target. Economic efficiency (E) is the percentage of maximum payoffs earned by the group.[19] Strict biological efficiency (SB) is a discrete measure of efficiency—either the group coordinates (1) or it does not (0). SB measures the percentage that the groups achieved the desired conservation objective. Weak biological efficiency (WB) is a gradient measure—the percentage of the desired conservation objective achieved by the groups.[20] If a group coordinates to the desired habitat, all efficiency measures equal unity (i.e., E = SB = WB = 100%).[21] For expediency, we let the three efficiency measures be average group outcomes for 10 round intervals {1-10, 11-20, 21-30} for each conservation treatment. We focus on group outcomes to determine the absolute effectiveness of the agglomeration bonus because the

[19] Appendix C presents the round-by-round economic efficiency by treatment.
[20] We use Figure 4 to clarify the WB gradient. In round 1, 11 of 24 cells needed to meet the desired core objective are conserved, implying WB = 45.8%. In round 2, WB = 37.5% (9 of 24 cells conserved); in round 5, WB = 75% (18 of 24 cells conserved); in round 9, WB = 91.7% (22 of 24 cells conserved).
[21] To illustrate, economic and biological efficiency are the mean values for rounds 1-10, 11-20, and 21-30.

group outcome is the most precise measure of effectiveness since here all four members of a group have to select the payoff dominant strategy for the group outcome to be considered *first best*.

Table 3 and Figure 5 illustrate the strict efficiency results for each conservation target by ABA rounds. We examine each conservation objective in turn. *Corridor*. For the corridor treatment, both economic efficiency and strict biological efficiency increase with experience. E increases from 88.8% in rounds 1-10, to 97.3% in rounds 11-20, and 100% in rounds 21-30. SB begins at 37.5% in rounds 1-10, increases to 72.5% in rounds 11-20, and in rounds 21-30 a 100% of all groups achieved the desired corridor objective. *Core*. SB is lowest for the core treatment rounds 11-20, 1.3%. In rounds 1-10 SB is 31.3% and increases to 76.3% in rounds 21-30. E for the core does not show the same variation as SB, 92.9% in rounds 1-10, 92.5% in rounds 11-20, and 98.4% in rounds 21-30. *Cross*. The cross treatment was only conducted in rounds 11-20, and efficiency measures are {E=94.2%; SB=30%}. *Corner*. The corner conservation objective exhibits a large variation in SB but not much variation in E, which results from subjects earning maximum payoffs while locating their habitat on the common column border—a Pareto inferior conservation strategy. SB is greatest in rounds 11-20, 75%. In rounds 1-10 and 21-30, SB is 45% and 50%. In rounds 1-10, E is 97.5%, in rounds 11-20, 99.7%, and in rounds 21-30, 99.4%.

We now state our second key result based on strict biological efficiency.

Result 2: *(a) For strict bioeconomic efficiency, the agglomeration bonus was the most successful in achieving the first best outcome for the corridor conservation objective in rounds 21-30. The agglomeration bonus was more successful in achieving the four-corners conservation objective in rounds 1-20. (b) As expected, for experienced subjects, strict bioeconomic efficiency is lower when the complexity of the coordination problem* *increases in the sense that all four players must coordinate to maximize payoffs (e.g., core and cross treatments)—i.e., more coordination failures.*

Support. For *Result 2a*, in rounds 1-20, we test the null hypothesis that the four corners conservation objective has a smaller probability of achieving strict bioeconomic efficiency. We examine both economic efficiency and strict biological efficiency. For economic efficiency we reject the null hypothesis at the 1% significance level (H_o: F(corridor, 1-20) $\geq$ G(corner, 1-20), $T_1 = 0.45$, p-value = 0.01; H_o: F(core, 1-20) $\geq$ G(corner, 1-20), $T_1 = 0.80$, p-value < 0.001; H_o: F(cross, 11-20) $\geq$ G(corner, 11-20), $T_1 = 0.30$, p-value < 0.025).[22] Economic efficiency for the four corners treatment is significantly larger than the economic efficiency of the core, corridor, and cross treatments. Using a Chi-square probability test, we reject the null hypothesis for strict biological efficiency at the 1% significance level for the core treatment, but we cannot rejected the null for the corridor treatment ($P_{core,1\text{-}20} \geq P_{corner,1\text{-}20}$, $T_1 = -6.25$, p-value < 0.001; $P_{corner,1\text{-}20} \geq P_{corridor,1\text{-}20}$, $T_1 = -0.81$, p-value = 0.209).[23] In rounds 21-30, we test the null hypothesis that the corridor conservation objective has a smaller probability of achieving strict bioeconomic efficiency than the core and four corners objectives. For relative economic efficiency in the corridor and core treatments, we reject the null hypothesis at the 1% significance level (H_o: F(core, 21-30) $\geq$ G(corridor, 21-30), $T_1 = 1$, p-value < 0.001). We cannot, however, reject the null hypothesis when comparing economic efficiency between the corridor and four corner treatments (H_o: F(corner, 21-30) $\geq$ G(corridor, 21-30), $T_1 = 0.20$, p-value > 0.10). For strict biological efficiency, we reject the null hypothesis at the 1% significance level ($P_{core,21\text{-}30} \geq P_{corridor,21\text{-}30}$, $T_1 = -3.36$

[22] We use a non-parametric Smirnov test for economic efficiency. The Smirnov test tests if the two populations have identical distribution functions.

[23] We use a Chi-square probability test to test hypotheses regarding strict and weak biological efficiency.

p-value < 0.001; $P_{corner,21\text{-}30} \geq P_{corridor,21\text{-}30}$, T_1 = - 4.90, p-value < 0.001). In the corridor treatment, the probability of achieving the Pareto dominant Nash equilibrium was greater relative to the core or four corners treatments.

The null hypothesis for *Result 2b* is: for experienced subjects, strict bioeconomic is invariant to the complexity of the coordination problem. We reject the null hypothesis at the 1% significance level for economic efficiency (H_o: F(core, 11-30) ≥ G(corridor, 11-30), T_1 = 0.75, p-value < 0.001; H_o: F(cross, 11-20) ≥ G(corridor, 11-20), T_1 = 0.5, p-value = 0.05). We also reject the null hypothesis for strict biological efficiency at the 1% significance level for rounds 11-30 (H_o: $P_{core,11\text{-}30} \geq P_{corridor,11\text{-}30}$, T_1 = - 6.22, p-value < 0.001; H_o: $P_{cross,11\text{-}20} \geq P_{corridor,11\text{-}20}$, T_1 = - 2.46, p-value = 0.007). As the complexity of the coordination problem increases so does the frequency of coordination failure.

Table 3 and Figure 6 show weak biological efficiency by conservation target.[24] *Corridor:* we see economic and weak biological efficiency both increase with experience—{E=0.897; WB=0.75} in rounds 1-10 to {E=0.973; WB=0.941} in rounds 11-20, and finally to E=WB=100% in rounds 21-30. *Core:* economic and biological efficiency reach a low point in rounds 11-20—{E=0.925; WB=0.36}. Apparently, subjects experienced in other conservation objectives find it most difficult to coordinate to the core. For groups in the core in rounds 1-10 and again in rounds 21-30, economic and biological efficiency increase from {E=0.929; WB=0.736} in rounds 1-10 to {E=0.984; WB=0.93} in rounds 21-30. *Cross:* since subjects only faced the cross treatment in rounds 11-20, efficiency is {E=0.942; WB=0.739}. *Corner:* economic and biological efficiency was relatively high for all rounds. Efficiency was (E=0.975; WB=0.844) in rounds 1-10, which increased to {E=0.997; WB=0.938} in rounds 11-20

[24] To illustrate, economic and biological efficiency are the mean values for rounds 1-10, 11-20, and 21-30.

and {E=0.994, WB=0.942} in rounds 21-30. For the corridor, core, and corner treatments we see greater efficiency in the last ten rounds (21-30) relative to the first ten rounds (1-10), which supports the notion that players can learn to understand the incentives at work in the agglomeration bonus.

Our third result summarizes weak biological efficiency.

Result 3. *(a) We see weak biological efficiency is at a maximum for the corridor objective in rounds 21-30. Inexperienced subjects' (rounds 1-10) facing the corner objective have the greatest level of weak biological efficiency. (b) Again, as expected, for experienced subjects weak bioeconomic efficiency is lower when the complexity of the coordination problem increases in the sense that all four players must coordinate to maximize payoffs (e.g., core and cross treatments)—i.e., more players locating their conserved cells outside of the targeted area.*

Support. For *Result 3a,* we test the null hypothesis that the probability of conserving a targeted cell in rounds 21-30 is less in the corridor treatment than in the core and four corner treatments. We reject the hypothesis at the 1% significance level in all cases (H_o: $P_{core,21\text{-}30} \geq P_{corridor,21\text{-}30}$, T_1 = - 7.51, p-value < 0.001; H_o: $P_{corner,21\text{-}30} \geq P_{corridor,21\text{-}30}$, T_1 = - 6.91, p-value < 0.001). For rounds 1-10, we test the null hypothesis that the probability of conserving a targeted cell is less in the four corner treatment than in the corridor and core treatments (H_o: $P_{core,1\text{-}10} \geq P_{corner,1\text{-}10}$, T_1 = - 30.97, p-value < 0.001; H_o: $P_{coridor,1\text{-}10} \geq P_{corner,1\text{-}10}$, T_1 = - 5.79, p-value < 0.001). Again, in all cases, we reject the null at the 1% significance level. For *Result 3b*, we test the null that for experienced subjects, the probability of conserving a targeted cell is invariant to the complexity of the coordination problem. Again we reject the null at the 1% significance level for weak biological efficiency (H_o: $P_{core,11\text{-}30} \geq P_{corridor,11\text{-}30}$, T_1 = - 13.81, p-value < 0.001; H_o: $P_{cross,11\text{-}20} \geq P_{corridor,11\text{-}20}$, T_1 = - 11.25, p-value < 0.001). More complexity in coordination decreases the frequency of conserving targeted cells.

Conclusion

Critics complain about the Endangered Species Act's inability to protect listed species on private lands. The ESA creates perverse incentives to landowners, which drive them either to bear the costs of species protection or to destroy habitat. Compensating landowners can help align their land use decisions with the objectives of the ESA (Bean, 1998). The challenge is to provide a compensation mechanism that is both voluntary and can target specific habitat that falls across private property lines. One mechanism is the agglomeration bonus. By making participation voluntary, the agglomeration bonus creates a setting that aligns landowners' incentives and species protection goals into contiguous habitat preserves.

Herein we explore whether the agglomeration bonus can induce groups of players to create voluntarily four spatial habitat designs: a corridor, a core, a cross, and four corners. Our result suggests the agglomeration bonus can work, especially once players gain experience with the mechanism. We observed the bonus was the most successful in achieving the first best habitat outcome for the corridor objective. Coordination to the core and cross objectives was more challenging because they required all four players to align their actions. Voluntarily creating four corners was relatively unproblematic—experienced subjects found the first- and second-best corners 100 percent of the time. Interestingly, coordination failure to fragmented habitat in the core treatment was more likely if players first had incentive to create the four corners. Initial isolation incentives made it more difficult to convince players to coordinate at the core even when it was more profitable.

Applying policies like the agglomeration bonus in the wilds can be assisted by the insight gained from testbed treatment. Our findings suggest that to reduce the risk of fragmented habitat, a regulator should understand the degree to which adjacent landowners are already coordinating their everyday activities. A second safeguard against fragmented habitat could be to introduce the agglomeration bonus at public meetings with as many of the local landowners present as possible. Finally, regulators might benefit from additional work examining how coordination changes with steeper payoffs, asymmetric landowner values, and combined incentive mechanisms, e.g., the agglomeration bonus linked with tradable development permits.

References

Alpern, S. and D. Reyniers 2002. “Spatial Dispersion as a Dynamic Coordination Problem,” *Theory and Decision* 53, 29-59.

Bean, M. J., 1998. “The Endangered Species Act and Private Land: Four Lessons Learned From the Past Quarter Century,” *Environmental Law Reporter News and Analysis* 10701-10710.

Bean, M. J., 1999. “Endangered Species, Endangered Act?” *Environment.* 41, 12.

Beier, P., and R.F. Noss, 1998. “Do Habitat Corridors Provide Connectivity?” *Conservation Biology* 12, 1241-1252.

Brown, G., and J. Shogren, 1998. “Economics of the Endangered Species Act,” *Journal of Economic Perspectives* 12, 3-18.

Berninghaus, S. K., and K. M. Ehrhart. 1998. “Time Horizon and Equilibrium Selection in Tacit Coordination Games: Experimental Results,” *Journal of Economic Behavior and Organization* 37, 231-248.

Black-footed Ferret Recovery Implementation Team (BFFRIT), 2002. “Black-Footed Ferret: Ferret Facts,” http://www.blackfootedferret.org/, [cited 5\20\02].

Conover, W. J., 1999. *Practical Nonparametric Statistics*, 3rd edition. New York: John Wiley and Sons, INC.

Cooper, R. 1999. *Coordination Games*: *Complementarities and Macroeconomics*. New York: Cambridge University Press.

Cooper, R. W., D. V. DeJong, R. Forsythe, and T. W. Ross. 1990. "Selection Criteria in Coordination Games: Some Experimental Results," *American Economic Review* 80, 218-233.

Cooper, R. W., D. V. DeJong, R. Forsythe, and T. W. Ross. 1992. "Communication in Coordination Games," *Quarterly Journal of Economics 107,* 739-771.

Crawford, V. P. 1998. “A Survey of Experiments on Communication via Cheap Talk,” *Journal of Economic Theory* 78, 286-298.

Diamond, J. M., 1976. “Island Biogeography and Conservation: Strategy and Limitations,” *Science* 193, 1027-1029.

Farrell, J. 1987. "Cheap talk, Coordination, and Entry," *Rand Journal of Economics* 18, 34-39.

Gilpin, M. E., and J. M. Diamond, 1980. "Subdivision of Nature Reserves and the Maintenance of Species Diversity," *Nature* 285, 567-568.

Harsanyi, J. C., and R. Selten. 1988. *General Theory of Equilibrium Selections in Games*. Cambridge, MA: The MIT Press, p. xi-378.

Higgs, A. J., M. B. Usher, 1980. "Should Nature Reserves be Large or Small?" *Nature* 285, 568-569.

Hof, J. and M. Bevers, 1998. *Spatial Optimization for Managed Ecosystems*. Columbia University Press, New York, NY.

Innes, R., S. Polasky, and J. Tschirhart, 1998. "Takings, Compensation and Endangered Species Protection on Private Lands," *Journal of Economic Perspectives* 12, 35-52.

McKenzie, E., 2003. "Important Criteria and Parameters of Wildlife Movement Corridors—A Partial Literature Review." http://www.silvafor.org/library/docs, [cited 5/13/2003].

Milgrom, P. and J. Roberts 1990. "Rationalizability and Learning in Games with Strategic Complementarities," *Econometrica* 58, 1255-1277.

National Research Council, 1993. *Setting Priorities for Land Conservation*, National Academy Press, Washington DC, pp. 259.

Noss, R., 1993. "The Wildlands Project Land Conservation Strategy," *GreenDisk Paperless Environmental Journal*. Feb-Mar, http://www.connix.com/~harry/nosswild.txt.

Ochs, J. 1995. "Coordination Problems," *Handbook of Experimental Economics* (J. Kagel and A. Roth, eds.) Princeton, NJ: Princeton University Press, pp. 195-251.

Parkhurst, G. M., J. F. Shogren, C. Bastian, P. Kivi, J. Donner, and R.B.W. Smith, 2002. "Agglomeration Bonus: An Incentive Mechanism to Reunite Fragmented Habitat for Biodiversity Conservation," *Ecological Economics* 41, 305-328.

Saunders, D. A., R. J. Hobbs, and C. R. Margules, 1991. "Biological Consequences of Ecosystem Fragmentation: A Review," *Conservation Biology* 5, 18-32.

Simberloff, D., J.A. Farr, J. Cox, and D.W. Mehlman, 1992. "Movement Corridors: Conservation Bargains or Poor Investments?" *Conservation Biology* 6, 4.

Schelling, T. C. (1960). *The Strategy of Conflict.* Cambridge, MA: Harvard Univ.

Smith, R.B.W., and J.F. Shogren, 2001. "Protecting Species on Private Lands," *Protecting Endangered Species in the United States,* J. Shogren and J. Tschirhart, eds. Cambridge Univ. Press, New York, pp. 326-342.

Smith, R.B.W., and J.F. Shogren, 2002. "Voluntary Incentive Design for Endangered Species Protection," *Journal of Environmental Economics and Management* 43, 169-187.

Terborgh, J., 1976. "Island Biogeography and Conservation: Strategy and Limitations," *Science.* 193, 1029-1030.

Van Huyck, J. B., R. C. Battalio, and R. O. Beil, 1990. "Tacit Coordination Games, Strategic Uncertainty, and Coordination Failure," *American Economic Review* 80, 234-248.

Van Huyck, J. B., R. C. Battalio, and R. O. Beil, 1991. "Strategic Uncertainty, Equilibrium Selection, and Coordination Failure in Average Opinion Games," *Quarterly Journal of Economics* 106, 885-911.

Vickrey, P., M. Hunter Jr., and M. Scott, 1994. "Effects of Habitat Area on the Distribution of Grassland Birds in Maine," *Conservation Biology* 8, 1087-1097.

Wilcove, D., M. Bean, R. Binnie and M. McMillan, 1996. *Rebuilding the Ark*. Environmental Defense, New York, NY.

Willis, E. O., 1984. "Conservation, Subdivision of Reserves, and the Anti-dismemberment Hypothesis," *OIKOS* 42, 396-398.

Whitcomb, R. F., J. F. Lynch, P. A. Opler, and C. S. Robbins, 1976. "Island Biogeography and Conservation: Strategy and Limitations," *Science* 193, 1030-1032.

Table 1. Treatments and Sessions. Four treatments were conducted: Corridor, Core, Corner, and Cross. The agglomeration bonus menu is presented for each treatment.

Sessions		Per Brown Cell Subsidy	Own Border Bonus	Row Border Bonus	Column Border Bonus	Number of participants (Rounds)
1&2	Corridor	$3	$8	$16	$0	16 (10)
	Core	3	16	13	8	16 (10)
	Corridor	3	8	16	0	16 (10)
3&4	Core	3	16	13	8	16 (10)
	Corridor	3	8	16	0	16 (10)
	Core	3	16	13	8	16 (10)
5&6	Core	3	16	13	8	16 (10)
	Corner	3	8	-5	-5	16 (10)
	Core	3	16	13	8	16 (10)
7	Corner	3	8	-5	-5	8 (10)
	Core	3	16	13	8	8 (10)
	Corner	3	8	-5	-5	8 (10)
8	Corner	3	8	-5	-5	8 (10)
	Core	3	16	13	8	8 (10)
9&10	Corner	3	8	-5	-5	16 (10)
	Cross	3	19	16	16	16 (10)

Table 2. Conservation Outcomes by Treatment

Incentive Design	Group Outcome		
	Optimal Conservation Configuration	Non-Optimal Contiguous Habitat Preserve	Fragmented Habitat
Corridor (All)	84 (70%)	9 (8%)	27 (22%)
Rounds 1-10	15 (38%)	2 (5%)	23 (58%)
Rounds 11-20	29 (73%)	7 (18%)	4 (10%)
Rounds 21-30	40 (100%)	0	0
Core (All)	87 (36%)	44 (18%)	109 (45%)
Rounds 1-10	25 (31%)	17 (21%)	38 (48%)
Rounds 11-20	1 (1%)	23 (29%)	56 (70%)
Corridor—Core	0 (0%)	21 (53%)	19 (47%)
Corner—Core	1 (2%)	3 (8%)	36 (90%)
Rounds 21-30	61 (76%)	4 (5%)	15 (19%)
Cross	12 (30%)	17 (43%)	11 (28%)
Rounds 11-20	12 (30%)	17 (43%)	11 (28%)
	Optimal Conservation Configuration	Non-Optimal, Four Isolated Habitat Reserves	More or Less Than Four Isolated Habitat Reserves
Corners (All)	76 (54%)	55 (39%)	9 (6%)
Rounds 1-10	36 (45%)	35 (44%)	9 (11%)
Rounds 11-20	30 (75%)	10 (25%)	0
Rounds 21-30	10 (50%)	10 (50%)	0

Table 3. Efficiency Measures by Treatment

Incentive Design	Group Outcome		
	SB Strict Biological Efficiency	WB Weak Biological Efficiency	E Economic Efficiency
Corridor			
Rounds 1-10	37.5%	75%	88.8%
Rounds 11-20	72.5%	94.1%	97.3%
Rounds 21-30	100%	100%	100%
Core			
Rounds 1-10	31.3%	73.6%	92.9%
Rounds 11-20	1.3%	36%	92.5%
Rounds 21-30	76.3%	93.1%	98.4%
Cross			
Rounds 11-20	30%	73.9%	94.2%
Corners			
Rounds 1-10	45%	84.4%	97.5%
Rounds 11-20	75%	95.8%	99.7%
Rounds 21-30	50%	94.2%	99.4%

Figure 1a. The 10x10 Experimental Land Grid

2	2	2	2	2	2	2	2	2	2
4	4	4	4	4	4	4	4	4	4
6	6	6	6	6	6	6	6	6	6
8	8	8	8	8	8	8	8	8	8
10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10
8	8	8	8	8	8	8	8	8	8
6	6	6	6	6	6	6	6	6	6
4	4	4	4	4	4	4	4	4	4
2	2	2	2	2	2	2	2	2	2

Figure 1b. General theoretical land grid

	1	2	3	4	5	6	7	8	9	10
1	$y_{U.1,1}$ $H_{U1,1}$	$y_{U1,2}$ $H_{U1,2}$	$y_{U1,3}$ $H_{U1,3}$	$y_{U1,4}$ $H_{U1,4}$	$y_{U1,5}$ $H_{U.1,5}$	$y_{C(1,6}$ $H_{C.1,6}$	$y_{C.1,7}$ $H_{C.1,7}$	$y_{C.1,8}$ $H_{C.1,8}$	$y_{C.1,9}$ $H_{C.1,9}$	$y_{C.1,10}$ $H_{C.1,10}$
2	$y_{U.2,1}$ $H_{U.2,1}$	$y_{U.2,2}$ $H_{U.2,2}$	$y_{U.2,3}$ $H_{U.2,3}$	$y_{U.2,4}$ $H_{U.2,4}$	$y_{U.2,5}$ $H_{U.2,5}$	$y_{C.2,6}$ $H_{C.2,6}$	$y_{C.2,7}$ $H_{C.2,7}$	$y_{C.2,8}$ $H_{C.2,8}$	$y_{C.2,9}$ $H_{C.2,9}$	$y_{C.2,10}$ $H_{C.2,10}$
3	$y_{U.3,1}$ $H_{U.3,1}$	$y_{U.3,2}$ $H_{U.3,2}$	$y_{U.3,3}$ $H_{U.3,3}$	$y_{U.3,4}$ $H_{U.3,4}$	$y_{U.3,5}$ $H_{U.3,5}$	$y_{C.3,6}$ $H_{C.3,6}$	$y_{C.3,7}$ $H_{C.3,7}$	$y_{C.3,8}$ $H_{C.3,8}$	$y_{C.3,9}$ $H_{C.3,9}$	$y_{C.3,10}$ $H_{C.3,10}$
4	$y_{U.4,1}$ $H_{U.4,1}$	$y_{U.4,2}$ $H_{U.4,2}$	$y_{U.4,3}$ $H_{U.4,3}$	$y_{U.4,4}$ $H_{U.4,4}$	$y_{U.4,5}$ $H_{U.4,5}$	$y_{C.4,6}$ $H_{C.4,6}$	$y_{C.4,7}$ $H_{C.4,7}$	$y_{C.4,8}$ $H_{C.4,8}$	$y_{C.4,9}$ $H_{C.4,9}$	$y_{C.4,10}$ $H_{C.4,10}$
5	$y_{U.5,1}$ $H_{U.5,1}$	$y_{U.5,2}$ $H_{U.5,2}$	$y_{U.5,3}$ $H_{U.5,3}$	$y_{U.5,4}$ $H_{U.5,4}$	$y_{U.5,5}$ $H_{U.5,5}$	$y_{C.5,6}$ $H_{C.5,6}$	$y_{C.5,7}$ $H_{C.5,7}$	$y_{C.5,8}$ $H_{C.5,8}$	$y_{C.5,9}$ $H_{C.5,9}$	$y_{C.5,10}$ $H_{C.5,10}$
6	$y_{R.6,1}$ $H_{R.6,1}$	$y_{R.6,2}$ $H_{R.6,2}$	$y_{R.6,3}$ $H_{R.6,3}$	$y_{R.6,4}$ $H_{R.6,4}$	$y_{R.6,5}$ $H_{R.6,5}$	$y_{A.6,6}$ $H_{A.6,6}$	$y_{A.6,7}$ $H_{A.6,7}$	$y_{A.6,8}$ $H_{A.6,8}$	$y_{A.6,9}$ $H_{A.6,9}$	$y_{A.6,10}$ $H_{A.6,10}$
7	$y_{R.7,1}$ $H_{R.7,1}$	$y_{R.7,2}$ $H_{R.7,2}$	$y_{R.7,3}$ $H_{R.7,3}$	$y_{R.7,4}$ $H_{R.7,4}$	$y_{R.7,5}$ $H_{R.7,5}$	$y_{A.7,6}$ $H_{A.7,6}$	$y_{A.7,7}$ $H_{A.7,7}$	$y_{A.7,8}$ $H_{A.7,8}$	$y_{A.7,9}$ $H_{A.7,9}$	$y_{A.7,10}$ $H_{A.7,10}$
8	$y_{R.8,1}$ $H_{R.8,1}$	$y_{R.8,2}$ $H_{R.8,2}$	$y_{R.8,3}$ $H_{R.8,3}$	$y_{R.8,4}$ $H_{R.8,4}$	$y_{R.8,5}$ $H_{R.8,5}$	$y_{A.8,6}$ $H_{A.8,6}$	$y_{A.8,7}$ $H_{A.8,7}$	$y_{A.8,8}$ $H_{A.8,8}$	$y_{A.8,9}$ $H_{A.8,9}$	$y_{A.8,10}$ $H_{A.8,10}$
9	$y_{R.9,1}$ $H_{R.9,1}$	$y_{R.9,2}$ $H_{R.9,2}$	$y_{R.9,3}$ $H_{R.9,3}$	$y_{R.9,4}$ $H_{R.9,4}$	$y_{R.9,5}$ $H_{R.9,5}$	$y_{A.9,6}$ $H_{A.9,6}$	$y_{A.9,7}$ $H_{A.9,7}$	$y_{A.9,8}$ $H_{A.9,8}$	$y_{A.9,9}$ $H_{A.9,9}$	$y_{A.9,10}$ $H_{A.9,10}$
10	$y_{R.10,1}$ $H_{R.10,1}$	$y_{R.10,2}$ $H_{R.10,2}$	$y_{R.10,3}$ $H_{R.10,3}$	$y_{R.10,4}$ $H_{R.10,4}$	$y_{R.10,5}$ $H_{R.10,5}$	$y_{A.10,6}$ $H_{A.10,6}$	$y_{A.10,7}$ $H_{A.10,7}$	$y_{A.10,8}$ $H_{A.10,8}$	$y_{A.10,9}$ $H_{A.10,9}$	$y_{A10,10}$ $H_{A10,10}$

Figure 2a. Core Conservation Objective

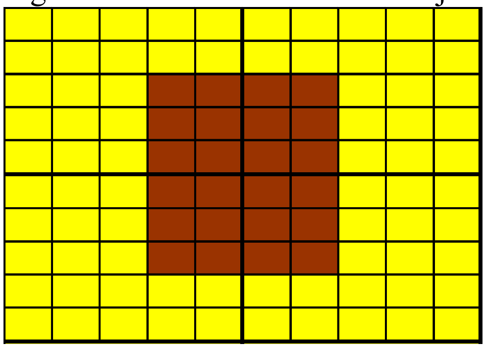

Figure 2b. Corridor Conservation Objective

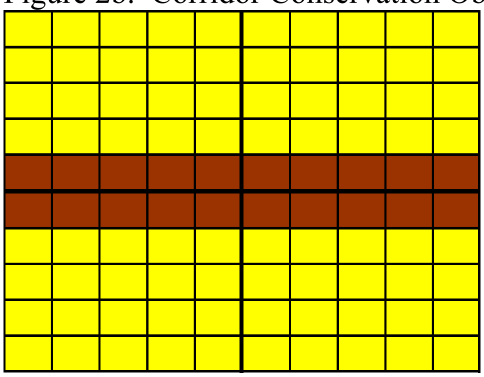

Figure 2c. Cross Conservation Objective

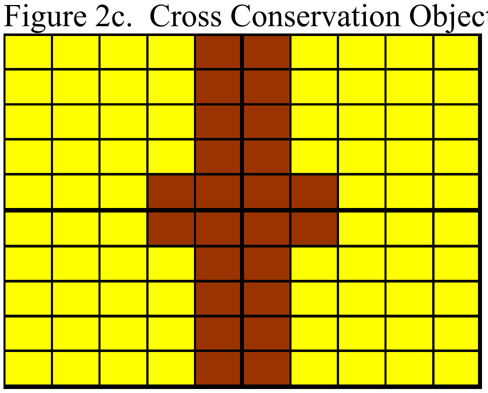

Figure 2d. Four Corners Conservation Objective

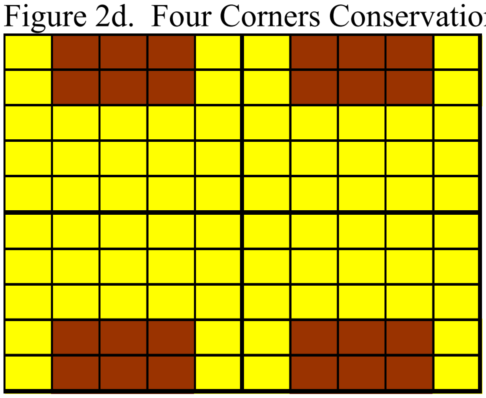

Figure 3a. Own Shared Border Bonus

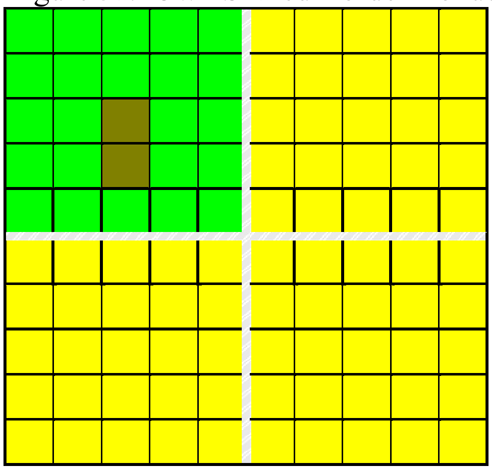

Figure 3b. Row Shared Border Bonus

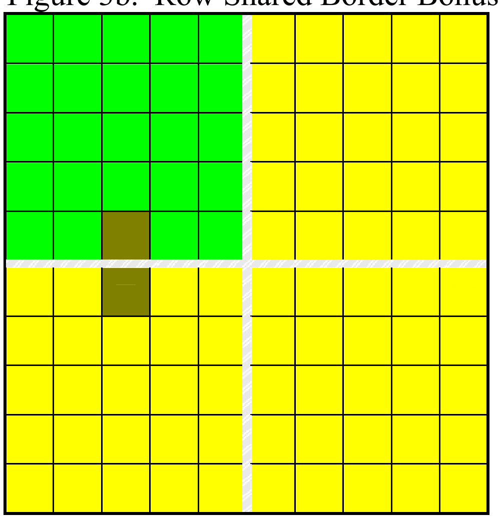

Figure 3c. Column Shared Border Bonus

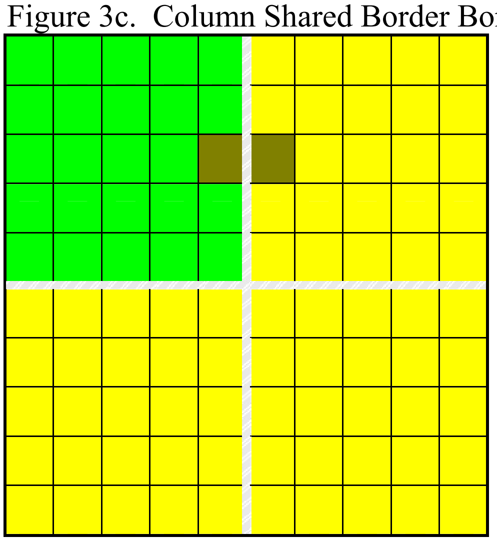

Figure 4. Example of Group Play in a Core-Corridor-Core Treatment by Round

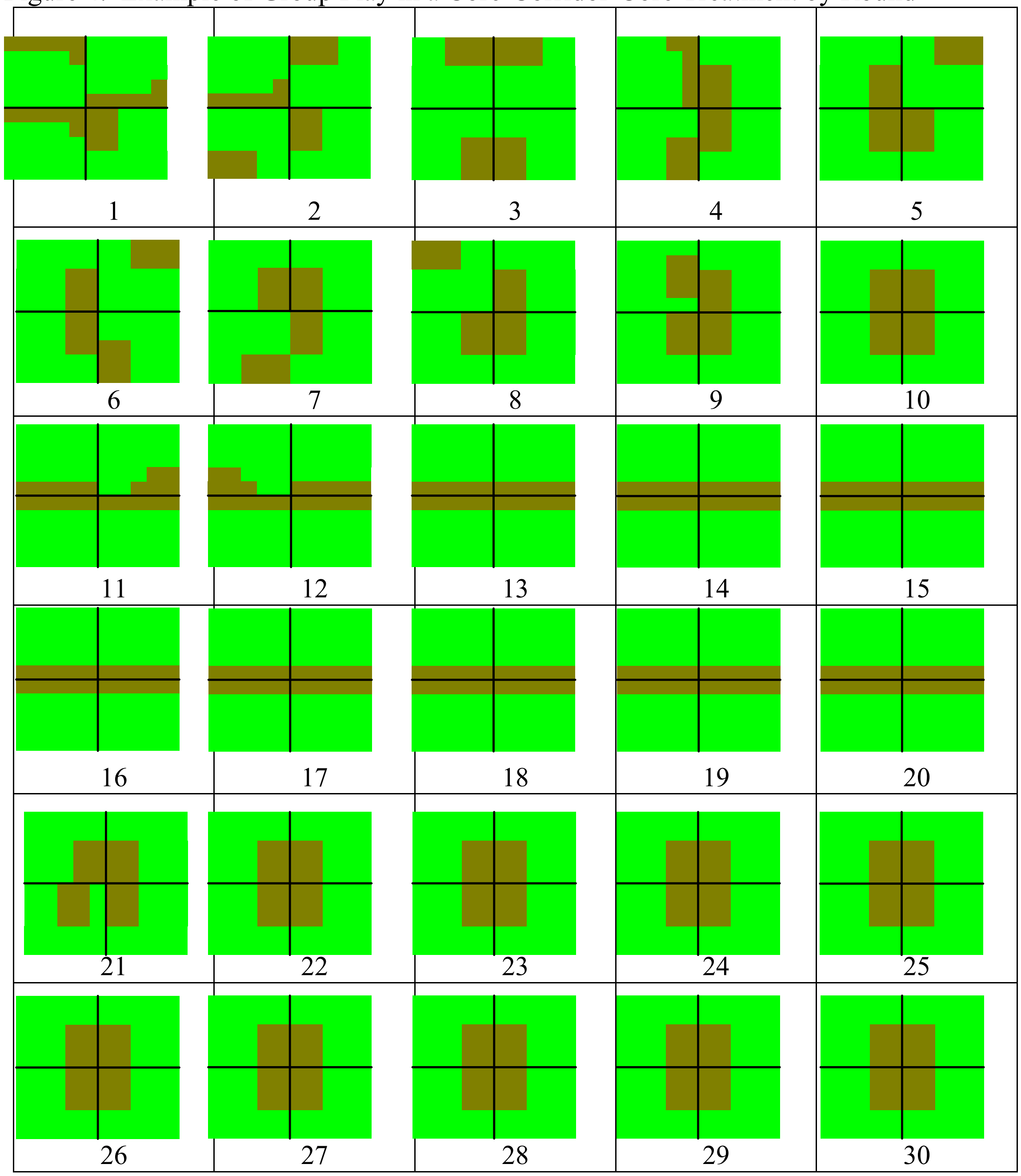

Figure 5. Strict Bioeconomic Efficiency

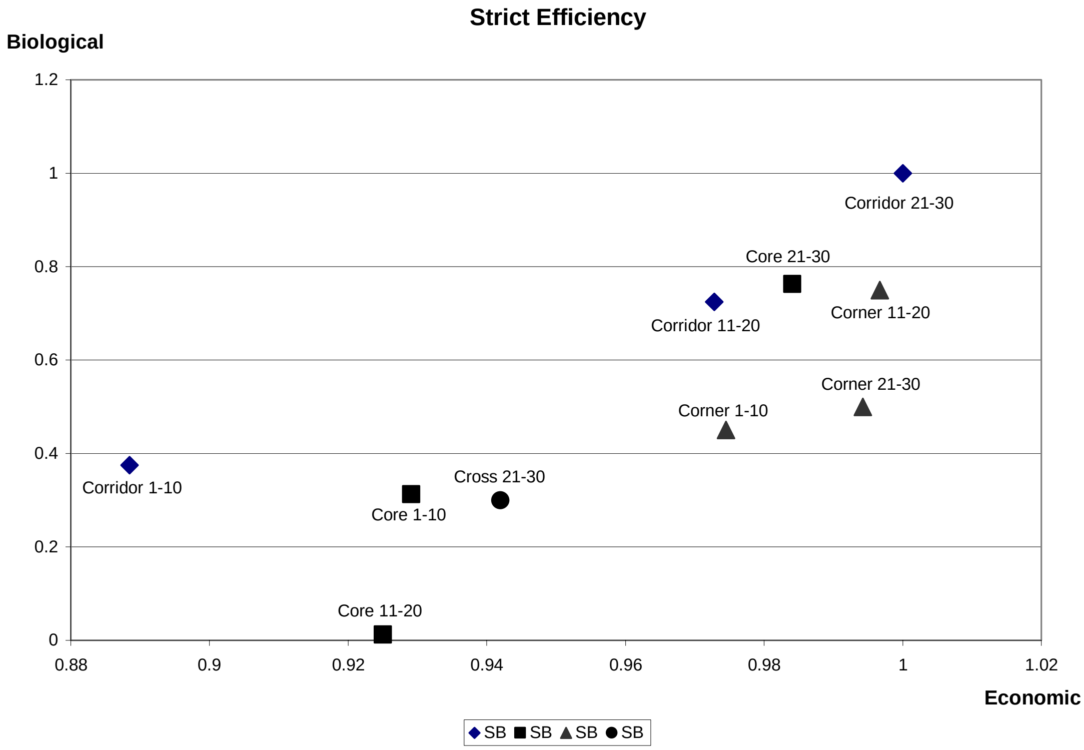

Figure 6. Weak Bioeconomic Efficiency