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# Reserve Selection in the presence of Economic Feedback Effects

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## Abstract

Targeting land for conservation has always been an important question. Studies so far have mostly assumed that biological and economic worlds operate in isolation from each other. This paper initiates the economic feedback effects into the reserve selection mechanism. With the help of heuristics, this paper shows that ignoring economic feedback effects can lead to sub-optimal conservation outcome and biased conservation estimates when we consider the biological value of land outside of nature reserves. The informed heuristic includes the amenity value effect in conservation planning process where as the informed-spatial heuristic adds spatial externalities to the model.

## 1. Introduction

Use of land to perform one function directly affects the availability of land for performing other functions[1] and indirectly affects the capacity of land to perform different functions via the external effects that each land use may generate. A good example of this can be seen in loss of habitats/open space because of increasing human activities. There is considerable evidence that human activities are encroaching on nature leading to loss of biodiversity and loss of ecosystem services (Pimm et al, 1995, Sala et al 2000, Luck et al, 2004). Human population density is positively correlated with deforestation in tropical forests and extinction rates of species (Luck et al 2004). Studies have shown that areas of human settlement and areas of high biological value coincide (Abbit et.al 2000; Dobson et al 2001; Scharlemann et. al 2004). Based on the evidence, it appears that conservation of biodiversity and ecosystem services should be a priority.

Primary threat to biodiversity loss is believed to be from habitat loss. Therefore there is a special need for conservation efforts to take place in or near areas where human demands on land are high as these are most often the areas which are more prone to loss. Efforts are already underway in that direction. Conservation policy relies heavily on land conservation. Setting aside land as nature reserves/protected habitats has been adopted as a way of preserving biodiversity. Targeting land for conservation has always been an important question. Between 1998 and 2001, more than $19 billion of public funds were appropriated through state and local initiatives for conservation objectives on private land

[1] This does not mean that land use practices are always mutually exclusive. Literature is replete with studies that focus on use of land for more than one function. But such uses are limited.

in United States (Newburn et al 2005). However there will never be enough money to protect all the valuable biodiversity.  It is important that we spend the resources at our disposal in the best possible manner. The problem of reserve selection is thereby a classic economic problem.

The huge literature on reserve selection deals with the question of how to optimally select a set of parcels to set aside as nature reserves. The research helps understand the practical issues/problems policy makers or decision makers deal with when faced with the choice of choosing parcels for nature reserves. Given that the land use practices are always evolving as a result of competing demands on this finite resource, reserve selection will ideally have to be a process which is ongoing and responds to various threats in a continuous manner. The decision makers are constrained by limited funds. That makes it difficult to choose all the sites that need to be chosen as reserves in one time period, making the process dynamic. Another real life feature of this problem is that not all the sites are available for conservation at a given time. The time at which a site becomes available for conservation may vary from site to site. The sites that are available this time period may not be available in the next. The threat of land conversion evolves over time responding to various drivers of land conversion and the feedback effects of economic variables. To be more specific, the probability of development faced by a land parcel is likely to change based on what is happening around the parcel. Just as the factors like development pressure for that landscape, distance to urban center will influence the probability of development a parcel faces; it is intuitive to expect the conservation decisions will also have an impact on it. Success of a conservation action will be contingent on the kind of impact it has on the other economic processes/variables, on how they react and affect the conservation outcome[2]. The conservation planning process will be more realistic when it accounts for the dynamic nature of the problem. Some of the other important factors to include/consider are heterogeneity in land quality and costs, externalities generated through the process and vulnerability of land to different threatening processes.

This paper attempts to highlight the complexities that arise when attempting to model some of the above mentioned factors. In most of the reserve selection literature, conservation planning has been modeled as operating in isolation from the world, that is, without any consideration of its feedback effects with the world. Conservation decisions made without considering their impact on other economic variables/conditions are likely to be sub-optimal. Conservation outcome measured without accounting for feedback effects is likely to be biased. The main objective of this paper is to initiate the economic feedback effects of conservation actions into the reserve selection process. It is necessary to consider these effects as economic and biological worlds do not operate in isolation from each other and resent evidence suggests that biodiversity is likely to occur in places of high human activities. Using simple numerical examples and simulations this paper shows that taking into account the economic feedback effects leads to more effective conservation results. Economic effects considered, are simple supply-demand movements along with the amenity value effect attached to nature reserves. The measure of vulnerability used here is the probability of development faced by each parcel on the landscape. Unlike most of the literature, probability of development faced by a land parcel is dynamic and to some extent endogenous in our model. There is a large body of literature which demonstrates that that adjacency between sites is an important factor

[2] By conservation outcome we mean the value of the objective function that the planner is trying to achieve.

contributing to species persistence on the reserves. Also on the other hand there exists a body of literature which highlights the amenity effects of open space or natural goods. This paper tries to bring together insights from the biological-spillover literature and the amenity value literature. There are a number of assumptions which the reserve selection literature has made as it evolved over the years. This paper incorporates relaxation of two of those assumptions. One of the important assumptions which not many studies do away with is that within protected areas, biodiversity will persist and outside them, it will perish. In this study parcels which are not chosen as reserves but are not developed retain their full biological value in the model. The other important assumption which is relaxed here is that costs and economic conditions are invariant over time. Details as to how this assumption is relaxes are narrated in a later section.

This paper is divided into following sections: Section 2 discusses the relevant literature, Section 3 presents the model, Section 4 presents the results of the heuristic algorithms and Section 5 offers conclusion and scope of future research.

## 2. Reserve-Selection Literature

Over the years researchers from diverse fields such as biology, operations research, and economics have contributed new methods of reserve selection to solve the problem of loss of species and habitats. Some of the earlier methods used by researchers included numerical scoring of sites to rank candidate sites in terms of multiple criterions, minimum set covering method and choosing sites based on complementarity value of each site. Soon it was realized that focusing on biological diversity objectives alone without considering costs was not realistic. The contribution that marks the beginning of the inclusion of economic factors into the reserve selection process literature is by Ando et al (1998).They show that in areas with varying per-unit land costs minimizing total cost may make more sense than minimizing total area. Polasky et al (2001) use land value data for Oregon along with the terrestrial vertebrate's data set to show that incorporating differential land costs in a budget constrained problem set up for locating natural reserves results in far more cost effective conservation. These contributions highlight the importance of considering the role of heterogeneity in land quality and costs in the process of reserve selection. Over the years research in this field has proceeded to devise ways to take into account more real life features of the reserve selection process. Newburn et al (2006) provide targeting strategy for protecting multiple environmental benefits that takes into account heterogeneity in both land costs and in probability of land use conversion. The authors try to show how positive correlation between land costs and probability of land-use conversion affects the efficiency of reserve site selection in a dynamic setting. Costello and Polasky (2004) analyze a dynamic reserve site selection problem in which sites must be chosen sequentially because of period specific budget constraint. Some sites are chosen after some of the threats of development are realized. The results indicate the importance of considerations of timing. They show that choosing sites before conversion risk is realized yields much higher expected conservation payoffs than choosing sites afterwards. However both Studies do not include spatial externalities in their analysis as well as consider the threat of development to be static in nature. Armsworth et al (2006) in a recent article consider how conservation purchases affect land prices and generate feedbacks that can undermine the conservation goals. This study attempts to deal with similar issues here.

Along with the economic factors it is important to consider the spatial structure of the reserves. The spatial nature of the reserves will play an important role in deciding if the species protected survive or not. Fragmented reserves will not promote the long term survival of species if the species needs demand connectivity. A number of researchers have incorporated spatial attributes into the reserve selection models (For example: Nalle et.al (2002), Onal and Briers (2002)). There exists a large body of research that deals with the spatial externalities that arise out of interdependent biological functions/values. (Albers 1996; Wu and Boggers 1999; Smith and Shogren 2002; Parkhurst et al. 2002; Polasky et al 2005). This body of research has tried to show that unless and until we account for these interdependencies in land use, the resulting land use patterns will not be efficient in that we could do better by accounting for them. The biological value of a parcel will not only be function of its own type/quality but it will also depend on the type /quality of its neighboring parcels and the activities pursued on them. It is thus important to consider the spatial spillover between reserve parcels as it will improve the conservation outcome.

There are a number of important feedback effects that can take place as a result of conservation actions. When the planner buys land for conservation, he reduces the supply of available land for other uses on the landscape. As per the simple demand-supply principles of economics, this will lead to an increase in the price of the remaining land parcels. The magnitude of the increase in land prices on this landscape will depend on the relative slopes of demand and supply curves for land (Armsworth et al, 2006). Another effect which may be seen is that the price for parcels adjacent to reserve parcels increases more than the increase in the price for the other parcels. For example studies by

Thorsnes(2002) and Turnes(2005) show that there is evidence for higher premium paid for land parcels next to nature reserves which captures the amenity-value spillover effects. Assuming that reserve parcels provide benefits such as scenic/aesthetic benefits, recreational opportunities, such parcels create amenity value. Based on the hedonic pricing studies it can be said that parcels that are adjacent to reserve parcels will have a premium attached to them because of the extra benefits they hold as compared to the other parcels. People will be willing to pay a higher price to live next to reserves. The direct effect of conservation action is to reduce the supply of land for other uses; the indirect effect of the same is to create the amenity value for the reserve parcels. Therefore we need to consider both the direct and indirect effects of the action taken by the conservation planner.

Another effect can take place following the reduced supply of land on a landscape as a result of conservation actions. Each parcel of land faces the threat of being developed; the probability of the same is determined by factors such as absolute location of the parcel on the landscape, distance from urban center, and availability of substitute land and development pressure for the landscape. These probabilities are not static, but are expected to be updated based on what happens on the landscape. By choosing a parcel for conservation, the planner increases the risk of development for the remaining parcels. Once again the increase in the probability will be distributed unevenly, with parcels adjacent to reserve parcel witnessing more increase in the probability of development as compared to the rest of the parcels. Irwin and Bockstael (2004) find that parcels with greater amounts of both preserved and unprotected open space nearby are more likely to have larger hazard rates of development, while more neighboring commercial and industrial development has a depressing effect on the hazard rate. This suggests that interaction effects tend to push new development away from areas with existing high density urban development and pull new development towards areas with yet undeveloped land. If such effects are sufficiently strong, they will foster an increasingly leapfrog or sprawled pattern of development. This finding supports our intuition/assumption that by choosing a single parcel as a reserve, the planner increases the risks for development of all the parcels on that landscape and more so for the adjacent parcels.

Assuming that the landscape is under acute development pressure and there is no substitute land available for the development to shift, as shown by Thornes (2002), Irwin and Bocksteal (2002) reserve parcels will act as attractors of development and we will see more increase in the probability of development of parcels surrounding the reserve parcels.

Thus following are the impacts that need to be considered:

1) Increase in the price of remaining land parcels of that landscape due to the reduced supply of land.
2) Increase in the price of land parcels adjacent to the reserves due to the amenity effect driven increase in demand specific to those land parcels.
3) Increase in the probability of development for all the parcels on the landscape because of reduced land supply
4) Increase in the probability of development faced by land parcels next to the reserve parcels due to amenity effect attracting development.

The above mentioned effects will take place under the assumptions mentioned earlier. If however planner's action leads to dispersal of development pressure from the landscape to some other landscape, then the effects that take place are may be of reduction in the probability of development and cost. This will depend on underlying demand-supply conditions for the concerned landscape and on assumptions about the development pressure faced by it. This paper focuses on the case where there is no dispersal of the development pressure. When the price of the remaining parcels increases on a landscape, it will make future conservation on that landscape costly. If reserve parcels act as attractors of development, then reserves may turn out to be fragmented. Fragmented reserves in turn can affect the conservation outcome in a negative manner. In this paper we test the response of conservation outcome when we factor in the amenity effect created by the reserve parcels.

## 3. Model

The landscape consists of j=1, 2…, J sites. We assume that each parcel has heterogeneous biological and economic value. Each parcel has a biological score denoted by $b_j$ which is a proxy for biodiversity on that parcel of land. Each parcel has an economic score denoted by $e_j$ which is a proxy for its economic productivity. The economic score is also interpreted as the economic cost of the parcel. It is assumed that all the sites are in the same state to begin with. Sites not chosen as reserves but not developed retain their biological value and are counted towards the biological score of the landscape. The planner starts with given probabilities of development faced by each land parcel at the beginning on the planning period and influences the probabilities in future periods by the actions he takes. The threat of development is thus partially endogenous in the model. Conservation decision as well as the development decision is assumed to be irreversible. To highlight complexity of the problem, we model four cases where one by one we add an additional component to the model.

### *3.1. Benefit-cost maximization:*

The first case takes into account the heterogeneous economic and biological values of each parcel. The planner's objective here is to maximize the biological score of the landscape given his budget constraint each time period. At the beginning of each time period, the planner will consider what is available for conservation, what has been conserved already and the budget for that time period and based on this information make his decision for that time period.

For this first case the planner's problem looks as follows:

$$\text{Max} \sum_{t=1}^{T} \sum_{j=1}^{J} \partial^{t-1} (b_j^{'}) X_{jt} \tag{1}$$

S.t.

$$X_{jt}^{'} e_j \leq M_t + m_t \tag{2}$$

$$N_{t+1} = N_t - X_t \tag{3}$$

$$R_{t+1} = R_t + X_t \tag{4}$$

$$M_{t+1} = (M_t + m_t - X_t^{'} e_j)(1 + a) \tag{5}$$

$N_0$, $R_0$, $M_0$ given.

Here bj and $e_j$ are Jx1 vectors. $X_{jt}$ is a J x 1 vector where $X_{jt}$ is equal to 1 if parcel j has been selected as a reserve in period t and 0 otherwise. $R_t$ is a Jx1 vector where $R_{jt}$ equals 1 if site j has been selected as a reserve before period t and 0 otherwise. Thus $R_{t+1} = R_t + X_t$ . $N_t$ is a Jx1 vector where $N_{jt}$ equals 1 is site j is available and not developed at the beginning of period t, 0 otherwise. The first constraint (equation 2) is a budget constraint for each time period. The planner gets $m_t$ in each time period. $M_t$ represents the amount of money that planner has, before receiving the budgeted amount in each time period. The money not spent in each time period is carried forward to the next time period with an interest at the rate of $\alpha$. The equations 2-4 are the equations of motion for each time period. This formulation follows closely from the one in Costello and Polasky (2004). This is a dynamic integer programming problem which can be solved recursively. In this case where there are no spatial/economic externalities or the threat of development faced by land parcels, in each time period the planner acquires parcels with highest $b_j/e_j$ ratio. As long as the benefits-cost ratio is higher than some threshold value or the shadow value of conservation funds, the planner will choose that parcel for conservation. This is a simple case where there are no interdependencies and the possibility of land parcels being developed is ignored completely. It captures the heterogeneous biological and economic values.

### *3.2. Expected Benefit-Cost maximization*

Here we add the uncertainty about each site being developed at the end of each time period to the first case leading to an expected benefit cost maximization problem. At the beginning of time period 1, the planner gets the information on probabilities of development faced by each land parcel. If the planner does not choose a site for conservation, it faces the threat of being developed at the end of the time period 1 with the given probability. The timing in this problem is as follows: At the beginning of each time period, the planner will take into account parcels available for conservation as well as the parcels already conserved and his budget and choose parcels for conservation in that time period. Then each parcel not chosen may be developed at the end of the time period with probability $p_{jt}$. The problem looks as follows:

$$\text{Max. } \sum_{t=1}^{T}\sum_{j=1}^{J} E_{Dt}\ (\partial^{t-1}(b_j^{'})X_j \qquad (1)$$

$$S.t.$$

$$X_{jt}^{'}e_j \le M_t + m_t \qquad (2)$$

$$N_{t+1} = N_t - X_t - D_t \qquad (3)$$

$$R_{t+1} = R_t + X_t \qquad (4)$$

$$M_{t+1} = (M_t + m_t - X_t^{'}e_j)(1+\partial) \qquad (5)$$

Where $D_t$ is Jx1 random vector which equals 1 when site j developed in period t, 0 otherwise. Equation 2 is the budget constraint for each time period and 3-5 are the equations of motion for the problem. This is a stochastic integer programming problem which can be solved numerically. However the problem becomes increasingly difficult as we add more sites (Costello & Polasky, 2004). As there is competition for land from developers now the planner has to consider the probability of development faced by each site along with its benefit-cost ratio. We know that at the beginning of the planning period (T+1), the planner would only consider the benefit-cost ratio without worrying about the probability of development. In the previous time periods benefit-cost ratio of each parcel will be weighed against the probability of development of each parcel. In a dynamic setting, it would justify to acquire a parcel with lower benefit-cost ratio but higher probability of development over a parcel with higher benefit-cost ratio and a lower probability of development.

### *3.3 Expected Benefit –Cost Maximization with economic feedback effects:*

This third case builds on the second case by making development a function of what has been conserved and the planner takes into account the consequences of his actions on the overall landscape. The probability of development faced by each parcel is a function of state of the parcels surrounding it and the conditions that define the development pressure for the landscape the parcel belongs to. The probability of development becomes $P_{jt}$ ($X_{jt,}$ Njt, Rjt, A). Here A captures the local land market conditions assumed. Specifically it denotes if the landscape under consideration is under high or low development pressure. The way the model works here is that at the beginning of each time period, the planner after observing the parcels available for conservation, parcels already conserved or developed, and the budget for that time period, chooses parcels for that time period. Based on the planner's decision and the structure of probabilities assumed, probabilities of development faced by the remaining parcels are updated. At the end of the time period, some development may occur before the planner gets to choose again at the beginning of the second time period. This problem becomes complex to solve very easily. In this paper, we try to incorporate the amenity-value feedback in reserve selection process with the help of a heuristic, the results of which will be discussed in section 4.

### *3.4 Adding biological spatial externalities to the previous case.*

Now we add conservation benefits created by spatial externalities to the previous case. Planner's objective in this problem set-up is to maximize the conservation score of the landscape by choosing parcels such that the spatial externalities are maximized too. It has been shown that spatial nature of the reserves is an important factor determining the success of conservation actions and thus is an important factor to consider. This paper incorporates this component in the informed-spatial heuristic algorithm. In this algorithm the notion of spatial externalities is operationalized by adding extra biological value when two parcels share a border. This is a very simple way of including spatial externalities and we plan to include a more rigorous biological model to depict the spatial externalities in future work.

## 4. Heuristic Algorithms

We make use of three heuristics to see the effect of introducing economic feedback effects into the conservation planning process. We assume heterogeneous economic and biological scores for each parcel. The landscape consists of six parcels. There are two time periods for each model. A Monte-Carlo experiment with 100 realizations in used to simulate the three algorithms. The biological score for each parcel and the economic score for each parcel are generated as random variables, $b_{jt} \sim U\ [1, 9]$ and $e_j \sim U\ [1, 9]$. The budget for each time period is drawn randomly, $m_t \sim U\ [2,7]$. The probability $P_{jt}$ for each parcel in each model is also a random variable, $P_{jt} \sim U\ [0.1, 0.8]$.

In the first heuristic algorithm called as the myopic heuristic, the planner maximizes the biological score of the landscape given his budget constraint for each time period. The threat of development is not considered by the planner here. Also the planner is not being foresighted here. In each time period, sites with highest benefit are selected as allowed by the period specific budget constraint. In each period, after the planner makes his selection, the probabilities update based on planner's decisions and development takes place at the end of that time period. It is assumed that development demand is constant at one parcel each time period. The biological score for the landscape at the end of the planning period consists of scores of the chosen sites plus the score of the sites not chosen but not developed.

In the second heuristic, called as the informed heuristic, the planner takes a foresighted/dynamic view of the future and thinks one period ahead. That is we calculate the expected value of the landscape in each case by solving for it recursively. He ranks each site based on expected contribution of the site chosen and of those not chosen but not developed at the end of the planning period. The site/s with highest expected biological score and satisfying the budget constraint gets chosen in that time period. The biological score of the landscape thus depends on not only the site/s chosen by the conservation planner but also on the expected contribution from sites not chosen but not developed. The informed heuristic assumes that the landscape under consideration is under high development pressure and there is no substitute land available, so the development pressure can not shift anywhere. This is the driving force for updating of the probabilities. If for example planner selects site one then the probability of development for its neighbors[3], site 2 and site 3 goes up by a certain number. The third heuristic algorithm called as the informed spatial heuristic adds the biological benefits of selecting sites that are adjacent to each other to the objective function of the planner. In this simple model, we represent the additional biological benefits as a constant number added to the biological score of each site per shared border. For example if site 2 and site 3 share a

[3] We define neighboring parcels based on shared borders. In this case where we have 2X3 grid for the landscape, parcel 1 has parcel 2 and 3 as its neighbors, parcel 2 has parcels 1 and 3 as its neighbors and so on.

border and are either conserved or not-conserved & not –developed ,then an additional point is added to each site's biological score.

The way development occurs in these three heuristics is as follows. We model two ways in which development can occur. In the first set up, at the end of each time period, after the planner has made his selection of parcels and after the probabilities have updated, the parcel with the highest probability of development is converted to development. In the second set up, at the end of each time period, from the remaining parcels one parcel is randomly selected for development. The motivation for doing this is to see the effect of strategic development versus random development on conservation outcome. It appears that there is more fragmentation on the landscape when the parcel with highest probability of development is developed.

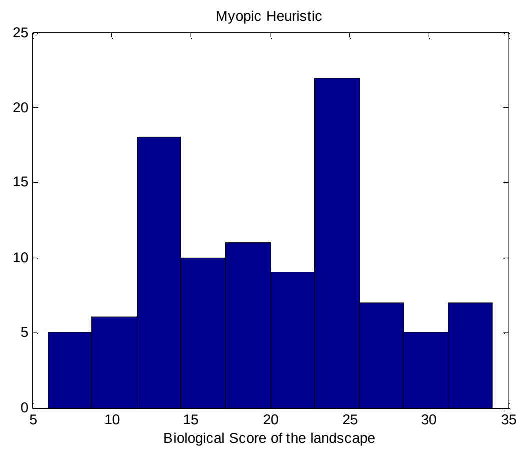
It can be seen that when the planner takes into account the feedback effect of his conservation decision on the probabilities of development for the other parcels on the landscape, the expected contribution of sites not chosen as reserves and not developed is adjusted downwards to reflect the feedback effect. The calculated conservation score at the end of the planning period is then a better signal of the increased threat of development and of the effectiveness of conservation action.

Table 1 shows the mean (as well as the standard deviation) biological score of the landscape under each simulation.

Table 1

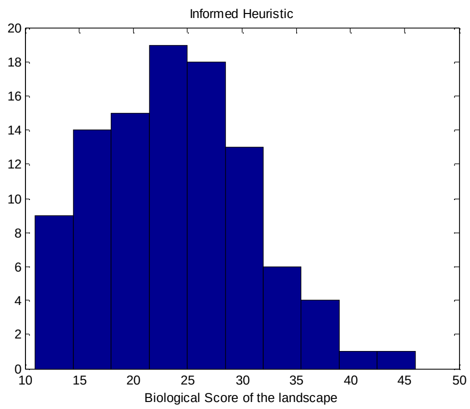
| | **Myopic Heuristic** | **Informed heuristic** | **Informed Spatial Heuristic** |
|---|---|---|---|
| *Mean* | 19.86 | 24.12 | 27.37 |
| *Std. Dev.* | 4.8 | 4.2 | 4.3 |

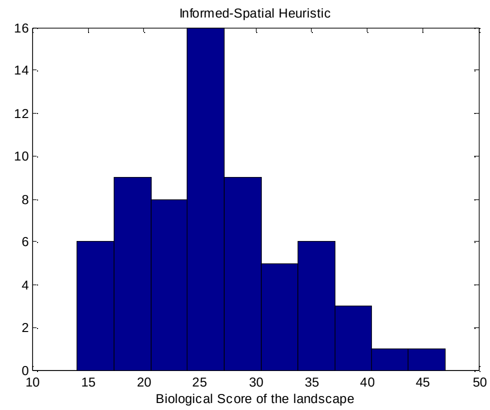
Figure 1 shows the distribution of the biological score for the landscape for the myopic heuristic algorithm.




Looking at the table we can see that the informed heuristic outperforms the myopic heuristic. The planner makes use of the information at his disposal to formulate a foresighted acquisition strategy given the uncertainty about development and the influence of his decisions on the threat of development for the remaining parcels. It is also important to note that of the 100 Monte Carlo simulations for more than 60 times the site ranking changed as we go from the myopic heuristic to the informed heuristic. The site ranked as the top site by myopic algorithm was no more the top site once we accounted for the updating probabilities of development. This suggests that the informed heuristic looks for a path of selection which will minimize the increase in the probability of development.

Figure 2 and 3 provide the distribution of expected values for 100 Monte Carlo simulations.




If the planner does not account for the updating probabilities based on his actions, then it will lead to an overestimation of benefits from the sites which are not reserved and not developed. Also it will lead to development of certain sites which may have not been developed otherwise. If parcels act as attractors of development, then conservation choices will have to be made more cautiously. In the third simulation, once we account for the biological benefits created by the spatial adjacencies, the expected conservation score increases as compared to the informed heuristic case as we would expect it to.

## 5. Conclusion

With the use of heuristics we show the effect of including one of the economic feedback effects in the conservation planning process. We looked at the amenity spill-over effect and how it can impact the biological value of the landscape. There are other effects that we list in the article but do not consider for analysis here which will be studied in future. This paper assumed for simplicity that the probabilities of development alone change and the cost of a parcel does not change. In reality however both probability of development faced by a parcel and the cost of the parcel are positively correlated.

Future study will relax this assumption. This paper uses simple biological scores as a proxy for biodiversity on the landscape, which is too simplistic. We plan to develop a detailed biological model for the biodiversity on the landscape in future. The preliminary results of this paper suggest that there is value in considering economic feedback effects.

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