GIS METHODS TO QUANTIFY EFFECTIVENESS AND LEAKAGE IN LAND CONSERVATION PROJECTS

Robert Gilmore Pontius Jr[1], Shaily Menon[2], Joseph Duncan[1] and Shalini Gupta[1]

[1]Clark University, Department of International Development, Community and Environment
[2]Grand Valley State University, Department of Biology

Abstract

The paper presents a GIS-based methodology to measure the effectiveness of efforts to conserve land while taking into consideration leakage. Effectiveness is measured in relation to the purpose of the conservation, which is biodiversity protection in India for the case that this paper analyzes. Leakage is the process whereby restrictions on land disturbance at one location do not eliminate the disturbance, but merely cause the disturbance to be displaced to a different location. If the displacement causes the disturbance to move from a location of high biodiversity to a location of low biodiversity, then the conservation project can still be effective in spite of the leakage. However, our results show that for the case of biodiversity in India, there is the distinct potential for the present network of conserved areas to cause leakage of disturbance from locations of medium biodiversity importance to locations of higher biodiversity importance, thus causing an unintended increase in threat to biodiversity. These principles apply to other types of land conservation projects, such as carbon offset projects called for by the Kyoto Protocol on climate change. This paper focuses on the general methods to quantify the conservation effectiveness in a manner that takes into consideration leakage. A land change model is at the core of the method, and this paper's particular application uses the Geomod model. An important implication of the results is that policy makers should consider conserving those locations that have the highest conservation value, not necessarily those that are under the largest threat.

Keywords

Biodiversity, change, India, model, scenario

1 Introduction

Some humans spend a tremendous amount of effort to change landscapes from a "natural" state to a "developed" state for a variety of desirable economic uses, such as urban, agriculture, transportation, mining, etc. Others spend a tremendous amount of effort to prevent such development in order to conserve the landscapes for a variety of important environmental uses, such as biodiversity maintenance, carbon storage, water filtration, soil stabilization, etc. It would be efficient in theory if a society were to focus its development efforts at locations that give the largest economic utility per area developed, and to focus its conservation efforts at locations that give the largest environmental utility per area conserved. However this is not necessarily the strategy of some influential conservation policies. Policy approaches, such as those in the Kyoto Protocol on climate change and the subsequent Bali Roadmap, call for conservation of land that is under imminent threat of new development, not necessarily of land that gives the largest utility for conservation. The apparent motivation for this type of strategy is to prevent development before it exerts its environmental impact. This strategy is nearly a perfect equation for escalation of conflict, because it motivates conservationists to prevent the actions that would otherwise be highest priority for developers. If the conservation is successful in preventing the development, then conservationists win and developers lose. A more likely outcome is that the conservation efforts would inspire developers to develop other available land. The process whereby conservation at one location causes development to shift from that location to another location is known as leakage. This paper lays a general conceptual foundation to analyze development, conservation, and leakage using land change modeling and Geographic Information Science. It is essential that scientists develop the founding principles for such analysis because such an approach will be used to make some of the most important economic and environmental decisions of this century. This paper illustrates the concepts with an application to biodiversity conservation in India.

2 Methods

2.1 Data

We compiled digital maps of India concerning elevation, vegetation, protected status, and species richness from the World Wildlife Fund, Environmental System Resources Institute, World Conservation and Monitoring Center, and the United States Geological Survey. All maps were georegistered in GIS as raster images with a resolution of one square kilometer per pixel. The values in the elevation map are binned in intervals of 100 meters. The categories of barren, cultivated, and cleared in the vegetation map were combined to generate a map of initial cleared, such that the non-cleared pixels indicate locations that have the potential for future anthropogenic development. Figure 1 superimposes the map of protected status on the map of initial cleared versus non-cleared.

We also generated a map of suitability for conservation based on three maps of plant, mammal, and bird richness. The resulting map of suitability for conservation gives high indices at locations of relatively high biodiversity concentrations and lower indices at locations of lower biodiversity concentrations.

2.2 Modeling approach

The land-use change model Geomod reads the map of initial cleared land and driver variables, which are potential vegetation and elevation for this case study. Geomod uses empirical analysis of these maps to generate a map of suitability for development, i.e. priority for additional future clearing. The value of each pixel in the suitability for development map is an index ranging from 0 to 100, where the relatively higher values indicate a combination of elevation and potential vegetation that makes those pixels relatively more attractive for development, according to Geomod’s empirical analysis (Pontius et al. 2001). We then use the suitability for development map to generate maps of future cleared status by searching among the non-cleared pixels for the largest suitability values and then converting them from non-cleared to cleared. All pixels that are cleared in the initial map remain cleared in the future, so Geomod simulates a one-way gain of cleared pixels as time progresses. Geomod’s first run produces a map in which half of the number of pixels that are non-cleared at the initial point in time become cleared in the future, where the selection of the location of the pixels is based exclusively on the suitability for development map. We select the quantity of future clearing as equal to half of the initial non-cleared pixels to illustrate the procedure. We do not have an estimate of the exact time in the future that is portrayed by the resulting map. Figure 3 gives the resulting map of the future cleared status, which is called the baseline scenario.

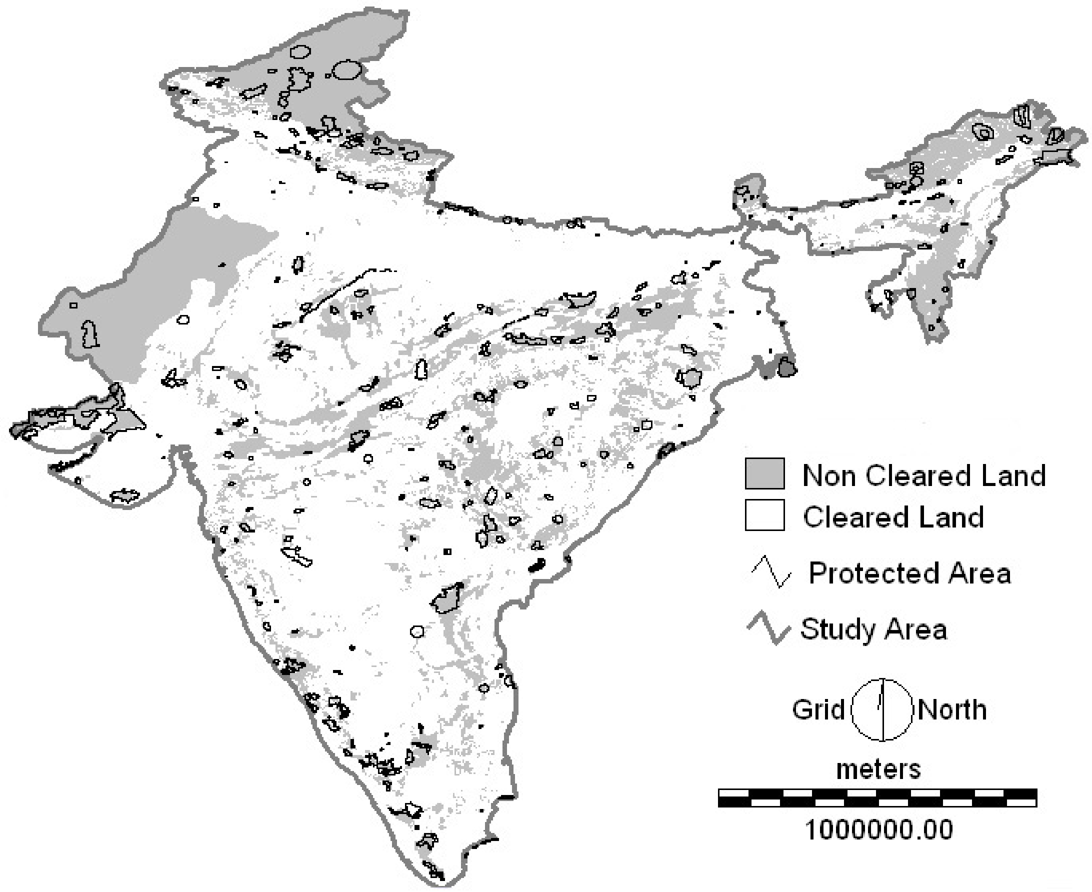

Figure 1. Initial cleared areas and protected areas.

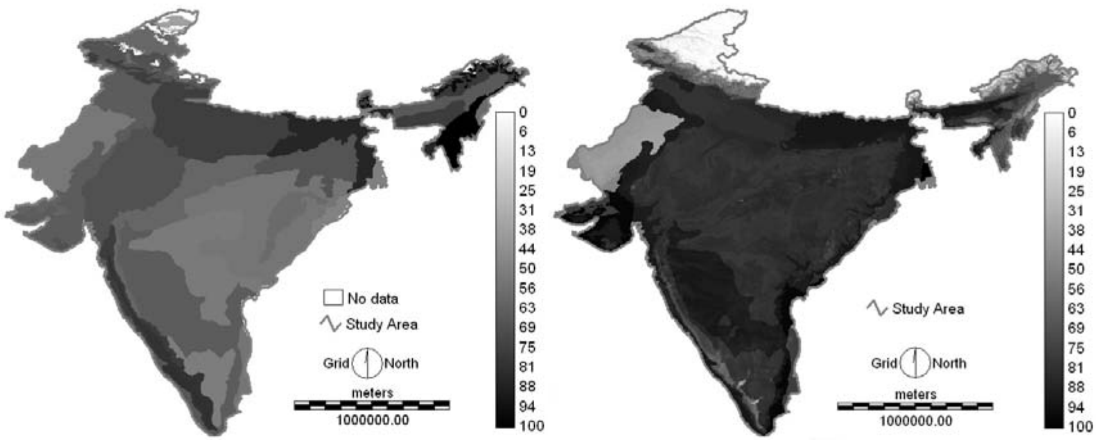

Figure 2. (a) Suitability for conservaiton on the left, and (b) suitability for development on the right.

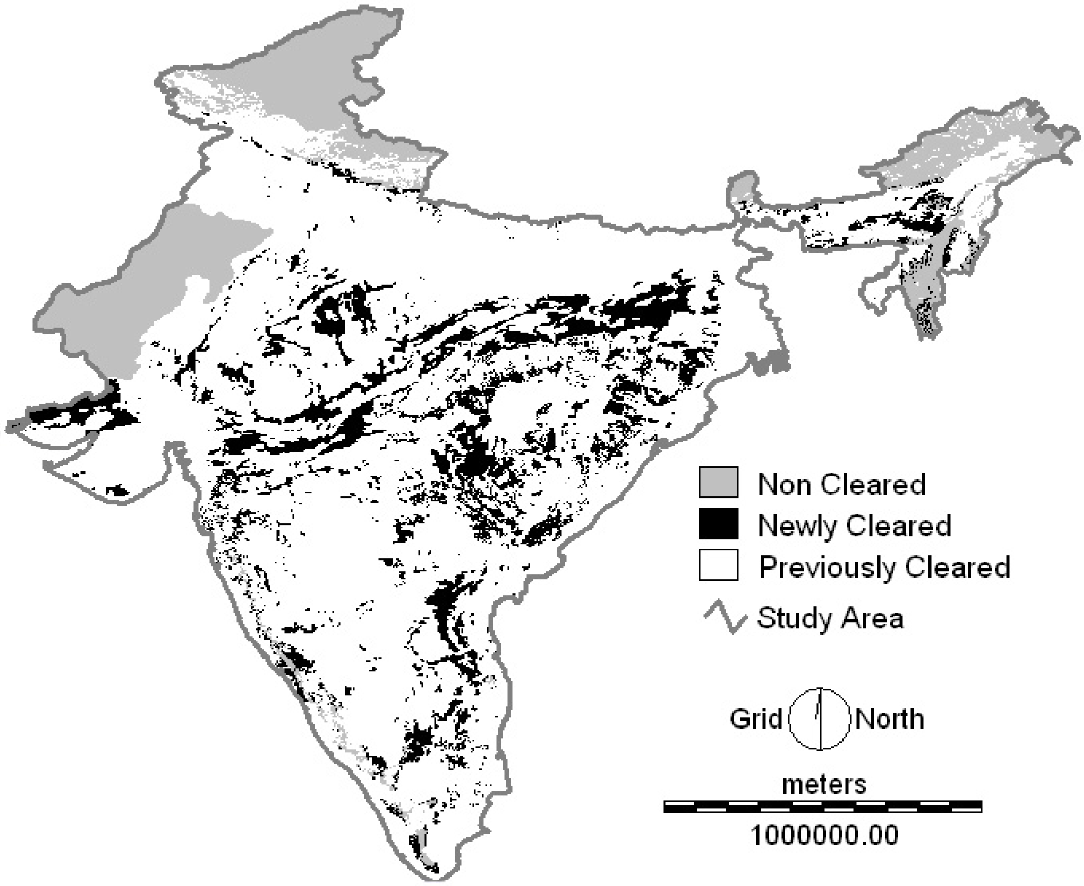

Figure 3. Baseline scenario of future where newly cleared areas occur in places of high suitability for development, regardless of protected status.

This baseline map is then overlaid with the map of protected areas to produce a map called the prevention scenario. This second scenario has a map where each pixel is assigned a category of cleared or non-cleared, but it has fewer newly cleared pixels than the baseline scenario, because newly cleared pixels in the baseline scenario that are also protected are reclassified as non-cleared in the prevention scenario. Thus, the prevention scenario portrays the case where the protected status is perfectly effective at preventing all new clearing that would have otherwise occurred had those locations not been protected. Alas, we suspect that the protection status would not simply eliminate development that would have otherwise occurred, since the effect of the protection is likely to displace future development from a protected location to an unprotected location, which is known as leakage. Therefore, we design a leakage scenario by first counting the difference in the number of newly cleared pixels between the baseline scenario and the prevention scenario. Then we modify the map of the prevention scenario to allocate this number of pixels of new clearing at unprotected locations that have the largest available suitability for development values. Hence the baseline scenario and the leakage scenario have the same number of newly cleared pixels from the initial time, but some of the pixels are in different locations due to leakage. Figure 4 shows these shifts in locations that are associated with leakage.

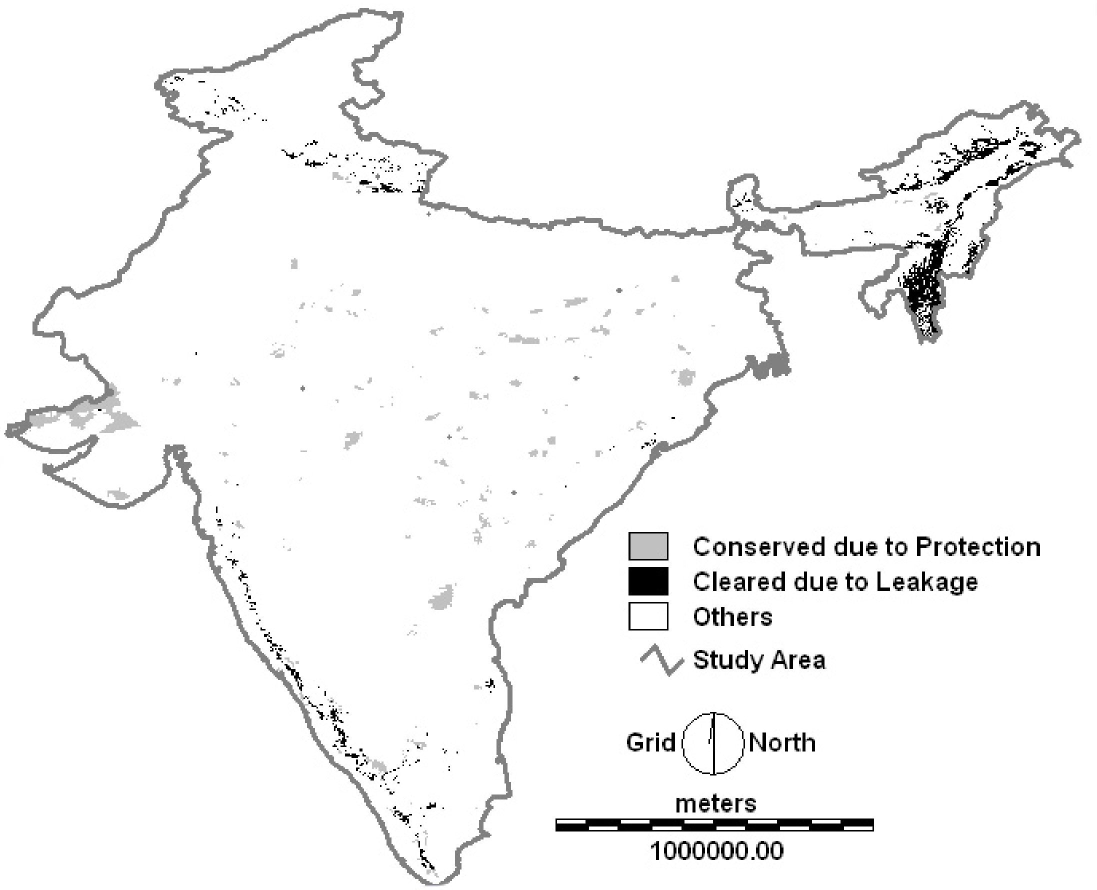

Figure 4. Map of displacement where where baseline clearing inside protected areas is displaced to locations outside protected areas.

If this shift in location causes the newly cleared pixels to move from a place of relatively high biodiversity to a place of lower biodiversity, then the consequences for conservation are positive relative to the baseline, in spite of the fact that the protection did not reduce the total area of new clearing. However, if this shift in location causes the newly cleared pixels to move from locations of low biodiversity to locations of higher biodiversity, then the consequences for conservation are negative. In order to measure this effect, we overlay a map of suitability for conservation on the land cover maps for each of the three future scenarios and the map of the initial point in time.

Figure 5a gives the theoretical framework to analyze the resulting numbers. The vertical axis shows the utility for conservation, which is computed as the sum of the suitability for conservation values in the pixels that are non-cleared in a map of land cover. The horizontal axis shows the utility for development, which is computed as the sum of the suitability for development values in the pixels that are cleared in a map of land cover. There are four land cover maps and each map corresponds to a single point in the space, with the map of the initial time residing at the dot in the upper left of the figure and the maps of the three future scenarios at the arrow heads in the lower right. These points are important in their position relative to each other, and not necessarily in terms of particular numbers along the axes.

It is helpful to describe each of the points in sequence. The map of the initial time shows the overall utility of the present landscape in terms of both conservation and development. At any point in time, the non-cleared areas give utility for conservation conceptualized in the form of ecosystem services. At the same time, the cleared areas give utility for development in the form of other types of economic services. All three future scenarios are to the right and below the initial time point because the scenarios portray landscapes that demonstrate an increase in future cleared land due to human development, so they necessarily have an increase in total utility for development and a decrease in total utility for conservation. The baseline scenario is farthest to the right because it places the new clearing at locations of highest suitability for development. Figure 5a shows the baseline scenario as lowest on the utility for conservation axis since the additional clearing occurs on land parcels regardless of their utility for conservation. Figure 5a portrays a situation where some of the land cleared in the baseline scenario occurs on protected land. This portion of the baseline clearing is eliminated in the prevention scenario, which is the next scenario in the sequence. Consequently, the point for the prevention scenario is to the left and above the point for the baseline scenario, since the prevention scenario has less newly cleared land than the baseline scenario. Lastly we examine the position of the point for the leakage scenario relative to the other points. The total amount of newly cleared pixels in the leakage scenario is identical to the amount in the baseline scenario; however the positions of the points in figure 5a are different due to differences in the scenarios concerning the locations of the newly cleared land. Figure 5a portrays a situation where the overall effect of the protected network is to displace future clearing from locations of relatively high suitability for conservation to locations of lower suitability for conservation. The leakage scenario point is to the left of the baseline point because the displacement necessarily causes new clearing to shift from locations of high suitability for development to locations of lower suitability for development. The leakage point is above the baseline point when the displacement causes new clearing to occur on land that has lower suitability for conservation. The leakage scenario has more newly cleared land than the prevention scenario; consequently the leakage point is below and to the right of the point for the prevention scenario.

It is helpful to assign names to the horizontal and vertical differences among the points. The vertical distance between the baseline point and the prevention point is the “intended benefit”. This is the amount of decrease in utility for conservation that the protection would prevent, if its effect were to eliminate new clearing on protected areas. The vertical distance between the points of the prevention scenario and the leakage scenario is a measure of the decrease in total utility for conservation due to leakage. The vertical distance between the leakage point and the baseline point is the resulting overall combined effects of protection and leakage on utility for conservation. If the leakage scenario point is above the baseline scenario, then the overall effect is positive, as portrayed in figure 5a as gain. Figure 5a expresses the gain in utility for conservation from the baseline as the intended benefit minus leakage. If the pixels of highest suitability for conservation are not protected, then it is possible in practice to have an unintended consequence that leakage causes clearing to shift from locations of lower suitability for conservation to locations of higher suitability for conservation, in which case the leakage point would be below the baseline point.

Similar analysis of the differences among the points can be made in terms of the utility for development. The horizontal difference between the baseline and prevention points is the initially posed threat to development, since it represents a reduction in the projected future baseline of growth in development. Developers can attempt to avoid this threat by shifting future clearing to unprotected locations, in which case they would not necessarily suffer the entirety of the projected drop in utility for development. This shifting activity allows them to “dodge” the initial threat posed by the protection. In the model, they shift their new clearing in the leakage scenario to their second best alternatives, so they are likely to recoup only partially the lost utility for development. Consequently, the horizontal difference between the leakage scenario and the baseline scenario is the effect of the protection network in terms of loss in utility for development from the baseline. Figure 5a expresses the loss in utility for development from the baseline as the posed threat minus the dodge.

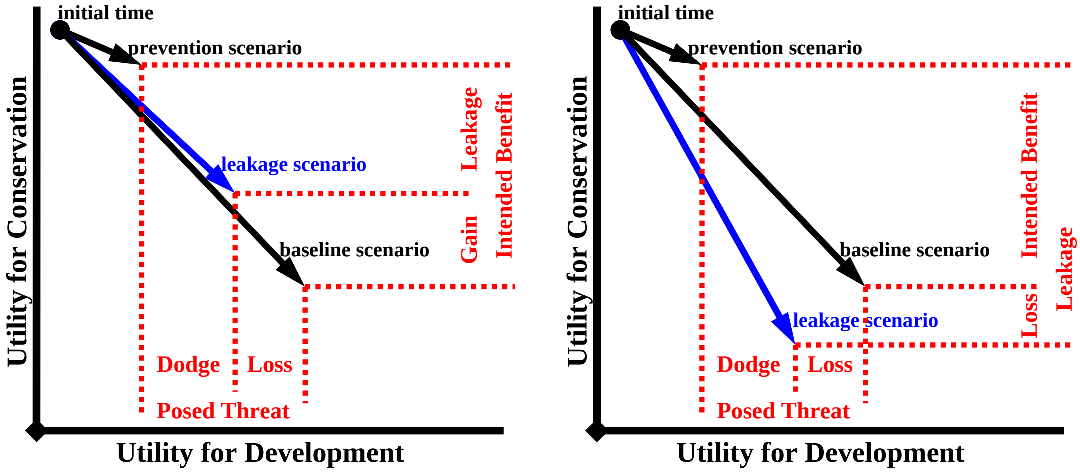

Figure 5. (a)Theoretical intended arrangement of points on the left, and (b) observed arrangement of points for the Indian case study on the right.

3 Results

The results of our modeling application to India illustrate a situation in which the leakage causes a displacement of future clearing from the baseline locations to other locations of relatively higher suitability for conservation. Figure 4 shows how the leakage causes clearing to move from locations scattered about the subcontinent to locations clustered in three regions that figure 2a shows as having very high suitability for conservation values: Western Ghats, Western Himalaya, and Northeast India. Consequently, the resulting arrangement of points in figure 5b is not consistent with the theoretical intended arrangement of points shown in figure 5a. Figure 5b shows that the resulting leakage point is below the baseline point. This portrays a situation where the efforts at protection have backfired, meaning that the combined effects of protection and leakage result in a landscape that has less utility for conservation than shown in the baseline scenario, since the leakage is larger than the intended benefit. At the same time, the leakage point is to the left of the baseline point, indicating that the combined effect of protection and leakage causes a loss in utility for development, since the protection prevents development from occurring at locations that the have the highest suitability for development. Hence, the results portray a lose-lose situation, where the leakage point shows a lower utility for both conservation and for development relative to the baseline point.

4 Discussion

Scientists must further develop both the concepts and procedures to measure leakage for a variety of applications (Aukland et al. 2002). Sathaye and Adrasko (2007) give many case studies for applications to carbon offset projects. One major general complication is that there are usually many goals for conservation. Stier and Seibert (2002) examine how efforts to manage carbon can be related to protection of biodiversity.

In the case of carbon, there is a natural unit of utility for conservation, i.e. mass of carbon dioxide emission equivalent. Furthermore, the total amount of carbon in the study area is the sum of the carbon in each pixel of the study area. Pricing mechanisms are designed to translate these units into monetary units, so that both axes of figure 6 can have the same meaningful units, in which case it might be reasonable to compare the tradeoffs between utility for conservation and utility for development. It is more challenging to match the units for conservation and development when the application is biodiversity. One reason is that the overall threat to biodiversity is not necessarily the sum of the threat in each pixel.

In our case study, we measured utility for conservation and utility for development as the sum of indices. We need to develop more insight into this aspect of our methods, since it assumes that the utility of the entire landscape is the sum of the utilities within pixels. This is fertile ground for the next stage in development of these concepts and methods.

5 Conclusions

This paper offers some bricks in the conceptual foundation for using GIS to assess effectiveness of conservation. We have used the concepts to show how the good intentions of ecosystem conservation can cause both conflict and leakage, which can cause a situation in which both conservationists and developers lose. If the land that has the largest value for conservation is protected regardless of the immediacy of the threat from development, then this lose-lose situation can be avoided, at least on theoretical grounds. The practical challenges in conceptualizing and in measuring leakage are enormous. Scientists should dedicate energy to address these challenges, because scientists will be asked increasingly to use these concepts to advise land policy in order to address some of the planet's most important economic and environmental crises.

Acknowledgements

The theses of Clark University students Amy Nelson, Nick Pieri, and Patrick Morris helped to establish the intellectual foundation of this paper. University of Massachusetts Professor Kamal Bawa supported this project, especially in acquiring data. The Michigan Space Grant Consortium and Grand Valley State University's Research and Development program contributed seed grants. The United States' National Science Foundation supported this work through the Center for Integrated Study of the Human Dimensions of Global Change at Carnegie Mellon University. Clark Labs has made the building blocks of this analysis available in the GIS software Idrisi®.

Literature

Aukland, L., Costa, P.M., and Brown, S. (2002) A conceptual framework for addressing leakage: the case of avoided deforestation. *Climate Policy* 3, pp. 123-136.

Pontius, R.G. Jr, Cornell, J. and Hall, C. (2001). Modeling the spatial pattern of land-use change with GEOMOD2: application and validation for Costa Rica. *Agriculture, Ecosystems & Environment* 85(1-3), pp. 191-203.

Sathaye, J.A. and Andrasko, K. (2007). Special issue on estimation of baselines and leakage in carbon mitigation forestry projects. *Mitigation and Adaptation Strategies for Global Change* 12, pp. 963-970.

Stier, S.C. and Siebert, S.F. (2002). The Kyoto Protocol: an Opportunity for Biodiversity Restoration Forestry, *Conservation Biology*, 16(3), pp. 575-576.