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Chapter 23

FUNDAMENTALS FOR USING GEOGRAPHIC INFORMATION SCIENCE TO MEASURE THE EFFECTIVENESS OF LAND CONSERVATION PROJECTS

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ABSTRACT

This chapter describes a general approach to use Geographic Information Science to assess the effectiveness of conservation projects that are designed to prevent anthropogenic land development from threatening ecosystem services. We illustrate the approach with an application to measure the effect of land protection on the preservation of biodiversity in part of the Indo-Malayan realm. The approach requires maps that show: initial land cover, independent variables associated with the drivers of anthropogenic land cover change, protected areas, and suitability for conservation. The land change model *Geomod* produces a map of suitability for development, which is then used to produce maps of extrapolated land development under three scenarios: Baseline, Prevention, and Leakage. Maps of these three scenarios are combined with the map of suitability for conservation to measure effectiveness of protection. The approach examines the consequence of leakage, in which conservation at protected locations has the effect of shifting anthropogenic land development from protected locations to unprotected locations. If the shift is from places of higher suitability for conservation to places of lower suitability for conservation, then the protection has an overall positive net effect at preserving ecosystem services relative to the baseline. However, the results for this chapter's application indicate that the effect of the protected areas is to shift development from places of lower biodiversity to places of higher biodiversity, because there are high biodiversity locations that have high suitability for development and are not protected. These results illustrate a situation where a conservation strategy can backfire when it

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aims to protect only the locations that are under threat and not the locations that maintain the most important ecosystem services. The methodology has been designed for use in a variety of contexts, specifically for policy applications that award credits for offset projects, for example carbon offset projects as called for by the Bali Roadmap for climate change.

Key Words: Conservation, GIS, land change, modeling, protected area

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, and mining. 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, and landslide prevention. 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 important conservation policies. Some policy approaches, such as those proposed by the Clean Development Mechanism of the Kyoto Protocol on climate change and the subsequent Bali Roadmap, call for conservation on land that is under imminent threat of new development, not necessarily on land that gives the largest environmental utility (Sedjo *et al.*, 1998; Clémençon, 2008).

The apparent motivation to focus policy strategies on land under immediate threat 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 are highest priority for developers. If conservation is effective in preventing development, then conservationists win and developers lose. If conservation is not effective in preventing development, then developers win and conservationists lose. A third plausible outcome of this policy strategy is that a conservation project might inspire developers to shift their future development from their first priority locations to their second priority locations. The process whereby conservation at one location causes development to shift from that location to another location is known as leakage. Leakage can undermine the overall effectiveness of a conservation project in terms of total environmental utility (Schwarze *et al.*, 2002). This chapter presents a general conceptual framework to assess the effectiveness of land conservation projects by using Geographic Information Science (GIS) and land change modeling to analyze development and conservation in the presence of leakage.

PROBLEM IDENTIFICATION / CONCEPTUAL BACKGROUND

There are two important challenges in the problem of measuring the effectiveness of a conservation project. The first is philosophical, the second is technological. The *philosophical challenge* is to design a procedure by which one can measure objectively the effectiveness of a land conservation project. Let us assume the land conservation project's mechanism is to place a legal restriction on a patch of undeveloped land in order to prevent the threat posed by future development. How can we measure whether the conservation project is effective in its overall goal to maintain the ecosystem services of undeveloped land? We need to consider two components. *First*, we need to assess the threat by development to that particular patch of undeveloped land. This can be done by envisioning a baseline scenario which portrays the development that would occur if the conservation project did not exist. *Second*, we must envision the influence of the conservation project on the actions of developers. If the conservation project prevents developers from their intended development on that patch, then the conservation project is successful in its goal to maintain ecosystem services on the protected patch. However, the conservation project might cause the developers to develop other parcels of land beyond the protected patch, through a process of leakage. We must consider this leakage when assessing the overall effectiveness of the conservation project. The project's overall effectiveness is the difference between the baseline scenario that lacks a conservation project and a scenario that has both the conservation project and leakage. This puts us in a challenging situation whereby we must design and assess a counterfactual scenario. The baseline scenario without the conservation project is counterfactual in the sense that it portrays how the developers would behave if there were no conservation project, while in fact there is a conservation project. Therefore, it is difficult to devise an objective method to assess the accuracy of the baseline scenario (Oreskes *et al.*, 1994). Furthermore, we must also assess how the conservation project influences the developers' differential impacts beyond the area of the conservation project. This is something that would probably be difficult for the developers themselves to quantify, due to the philosophical problem that it depends in part on a counterfactual baseline scenario. Some have proposed to address this problem by using GIS and land change modeling to generate the scenarios (Kerr *et al.*, 2003).

Even if the philosophical challenges can be overcome, there are *technological challenges* to using GIS and land change modeling to measure the effectiveness of conservation projects. GIS-based modeling techniques can be used to produce a map of the counterfactual baseline scenario to portray how the landscape would appear if there were no conservation project. GIS can be used also to generate a map to portray the landscape under the assumption that the conservation project completely prevents the hypothetical baseline development. Additional land change modeling could generate a map that portrays the landscape under a leakage scenario that assumes the conservation project causes developers to shift their development beyond the conservation project area. If scientists could produce all of these maps accurately, then they could measure the effectiveness of the conservation project by considering the differences among the maps. This would require a clear definition of development, a comprehensive understanding of the behavior of developers, a quantifiable definition of ecosystem services, a proper understanding of how development influences the environment, accurate data for all of the preceding, and a land change model that accurately predicts the behavior of developers under counterfactual scenarios. There exist many GIS-based models that are designed to generate maps of such land change scenarios. Whether there is any objectively measured justification to trust the usefulness of large complex models is another story (Lee, 1973). Herein lie many technological challenges.

These philosophical and technological challenges are enormous. If scientists fail to address these challenges promptly, then important environmental initiatives will fail because implementation of major policy proposals requires these types of measures of effectiveness. For example, policies that encourage offset credit trading require a project to quantify its effectiveness. If we wait for all the philosophical and technological challenges to be resolved perfectly, then it will be too late, because ecosystems around the world are already being degraded rapidly. Therefore, this chapter proposes a path forward to use the burgeoning fields of GIS and land change modeling to address the philosophical and technological challenges of measuring the effectiveness of efforts to protect the world's natural resources. This paper illustrates the concepts with an application to biodiversity conservation in the Indo-Malayan region.

REVIEW OF LITERATURE

For many years, scientists have been developing methods for land change modeling (Veldkamp and Lambin, 2001). There are a variety of approaches, each with its own data requirements. Such models typically predict a quantity of future anthropogenic development and then predict the spatial allocation of that development. It is possible to separate conceptually and mathematically the quantity of the area of future development from the spatial allocation of that development. For example, Pontius and Batchu (2003) and Pontius and Pacheco (2004) give methods to analyze the spatial allocation of development distinctly from the quantity of development for applications in the Western Ghats of India.

Agrawal *et al.* (2002) review many different land change models and expose a large range of techniques. Pontius *et al.* (2008) performed a validation exercise that compared the accuracy of the output maps for 13 different modeling applications from 9 different models and found that 12 of the 13 cases contained more error than correctly predicted change at the fine resolution of the raw data. They also found that the accuracy of the output maps seemed to be influenced more by the selection of the study site and the format of the data, than by the modeling technique, so there is no guarantee that more complex models will necessarily have higher levels of accuracy. In fact, Pontius *et al.* (2007) found that a very simple model that allocated deforestation adjacent to the Transamazon Highway was more accurate on a pixel-by-pixel basis than a more complex model that attempted to simulate the behavior of farmers in the Amazon.

GIS and land change modeling have been applied to generate baselines for land use and carbon. Applications include the prediction of sequestration for carbon-offset markets (Pfaff *et al.* 2000) and the estimation of the potential for carbon mitigation by agriculture (Smith et al. 2000). Sathaye and Andrasko (2007) give several case studies of land change modeling applied to measuring the effectiveness of conservation projects and the related leakage in the context of carbon offset projects. These methods build on the framework of Aukland *et al.* (2003). McDonald *et al.* (2007) examine historical maps to reveal how the protection of land in the past has influenced subsequent protection and development of neighboring lands at three sites in the United States. Menon *et al.* (2001) show how land change modeling can be used to target locations for conservation with an application in northern India.

A common complication is that there are usually many goals for any single conservation project. Stier and Seibert (2002) examine how efforts to manage carbon can be related to protection of biodiversity. Pearce and Perrings (1995) make explicit the link between development and biodiversity and call for a shift of focus from biodiversity as an asset unrelated to development to one that values biodiversity as an integral part of the development process.

Study Area

The study site for this chapter's example is the part of the Indian subcontinent for which we have data. It is helpful to use available empirical data to illustrate the overall approach because presentation of the data can illustrate clearly both the strengths and weaknesses of the analysis. Regardless of the quality of the data, the purpose of this chapter is to illustrate the concepts of conservation, development, and leakage in a general framework. The reader is encouraged to consider how these concepts play out in the context of biodiversity in the Indo-Malayan region and whether the available data are up to the task.

For leakage analysis, selection of the extent of the study area is extremely important. The study area should be the union of the land that is originally targeted for development, the land that is intended to be conserved, and the land where leakage could possibly occur. Hence, the selection of the extent can be a challenge since it can be difficult to know where the leakage might occur, especially before one performs the analysis. The selection of study extent is easiest when: (i) there is exactly one specific threat of development; (ii) there is exactly one conservation project; and (iii) the possibility of leakage is confined to be close to both the development threat and the conservation project. These three conditions typically occur in the case where slash & burn farming by small scale farmers is the threat, and there is a single proposed conservation project designed to conserve the threatened forests. There is a distinct likelihood that the farmers will simply walk outside the conservation area to begin slash & burn farming in the forests that are adjacent to the conservation area. In this case, the areas of development, conservation, and leakage are contained within a small contiguous extent. This design is common for some types of projects implemented by non-governmental organizations such as Conservation International.

However, if the process of development and conservation is much broader, then it can be more difficult to determine the appropriate study extent. For example, if the planned development is by multi-national corporations who plan to convert large segments of the Amazon forest to soy bean cultivation, then the conservation plan must be correspondingly larger, and the leakage could occur internationally. Conservation efforts in the Amazon could inspire agribusinesses to shift agricultural production from Brazil to Indonesia, in which case Indonesia would need to be included in the study area. One should select a study site that captures the entire phenomenon including leakage. Therefore, the selection of this chapter's study extent is appropriate for the type of development that can shift within the Indian subcontinent.

Tools / Materials

A spatial dataset for this analysis was compiled from maps of vegetation, protected areas, species richness, and elevation obtained from the World Wildlife Fund (WWF-US), Environmental System Resources Institute, World Conservation and Monitoring Centre, and the United States Geological Survey (online). The study area is constrained to be those parts of the Indo-Malayan realm shown in the maps from MacKinnon (1996). All data layers are 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 map of vegetation was reclassified to produce a map of cleared and non-cleared areas. Various vegetation categories, such as sub-tropical dry evergreen and evergreen forest, were reclassified as non-cleared areas and the remaining categories (cleared, barren and cultivated) were reclassified as cleared areas. The resulting map serves as the initial time land cover map in which 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.

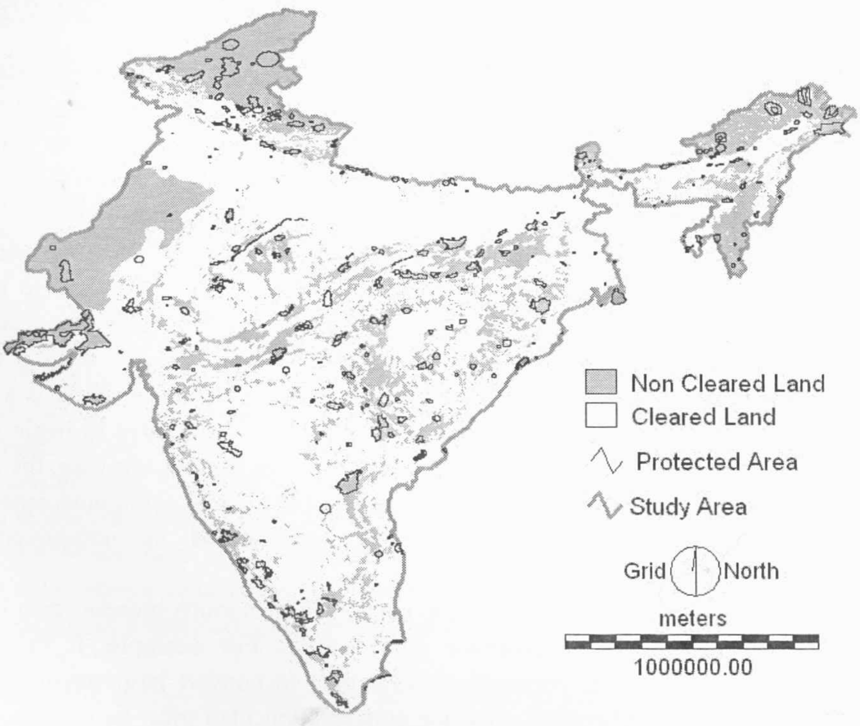

Figure 1. Protected areas overlaid on the initial time land cover

We also produced a map of suitability for conservation by aggregating three species layers (plant, mammal, and bird richness) and by comparing the result with a map of current status of biodiversity in the Indian subcontinent. The various biodiversity layers, with values that show species richness and endemism, were created by WWF-US during their ecoregions project (Olson and Dinerstein 1998; 2001). The values for bird, mammal, and plant richness show the number of species found in the various regions. Z-scores were computed for each of the input maps and then weights of 0.2, 0.2 and 0.6 were assigned to bird richness, mammal richness and plant richness respectively to create a weighted average of z-scores. We then rescaled the resulting map such that each pixel expresses an index for biodiversity between 0 and 100. Figure 2 shows the resulting product that serves as the suitability for conservation map, which gives high indices at locations of relatively high biodiversity concentrations and lower indices at locations of lower biodiversity concentrations.

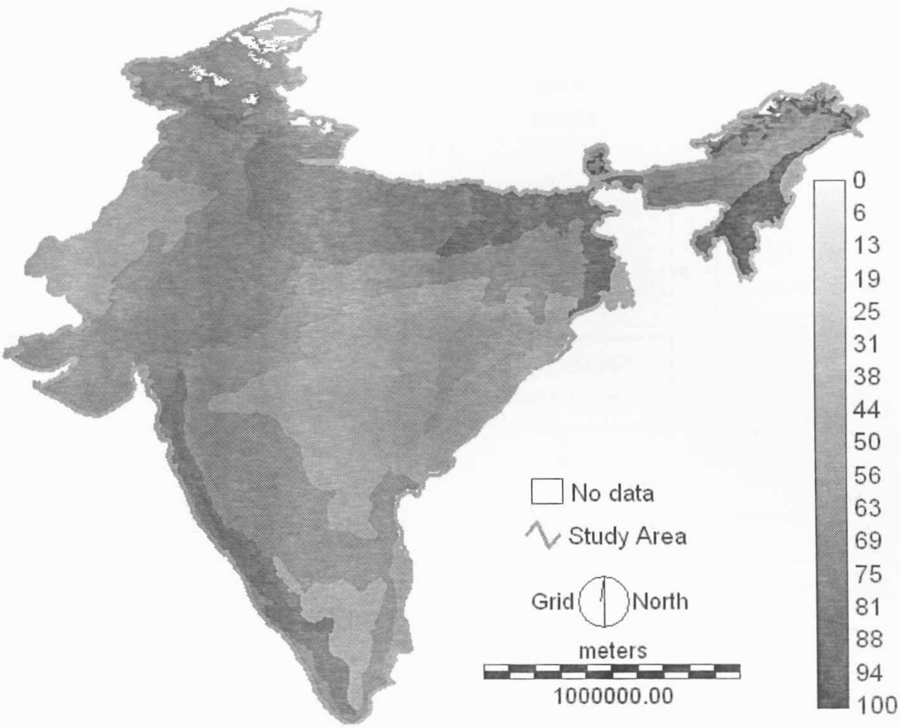

Figure 2. Suitability for conservation.

Methodology

Figure 3 indicates the flow of information in the overall analysis. The land-use change model Geomod reads the initial time land cover map and factor maps, which are vegetation type and elevation for this case study. Geomod uses empirical analysis of these maps to generate a map of suitability for development, which shows the order of the priority of the locations for the simulation of additional future clearing. Figure 4 shows this map where the value of each pixel is an index ranging from 0 to 100, where the relatively higher values indicate a combination of vegetation and elevation that makes those pixels relatively more attractive for development, according to Geomod's empirical analysis (Pontius *et al.*, 2001). Geomod 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 converting them from non-cleared to clear. 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 numbers of pixels that are non-cleared at the initial 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 time non-cleared pixels to illustrate the procedure. The time at which half the existing land cover would be cleared depends on the assumed rate of future development, and we do not specify the exact time in the future that is portrayed by the map of the scenario. Figure 5 gives the map of the future cleared status, which is called the baseline scenario.

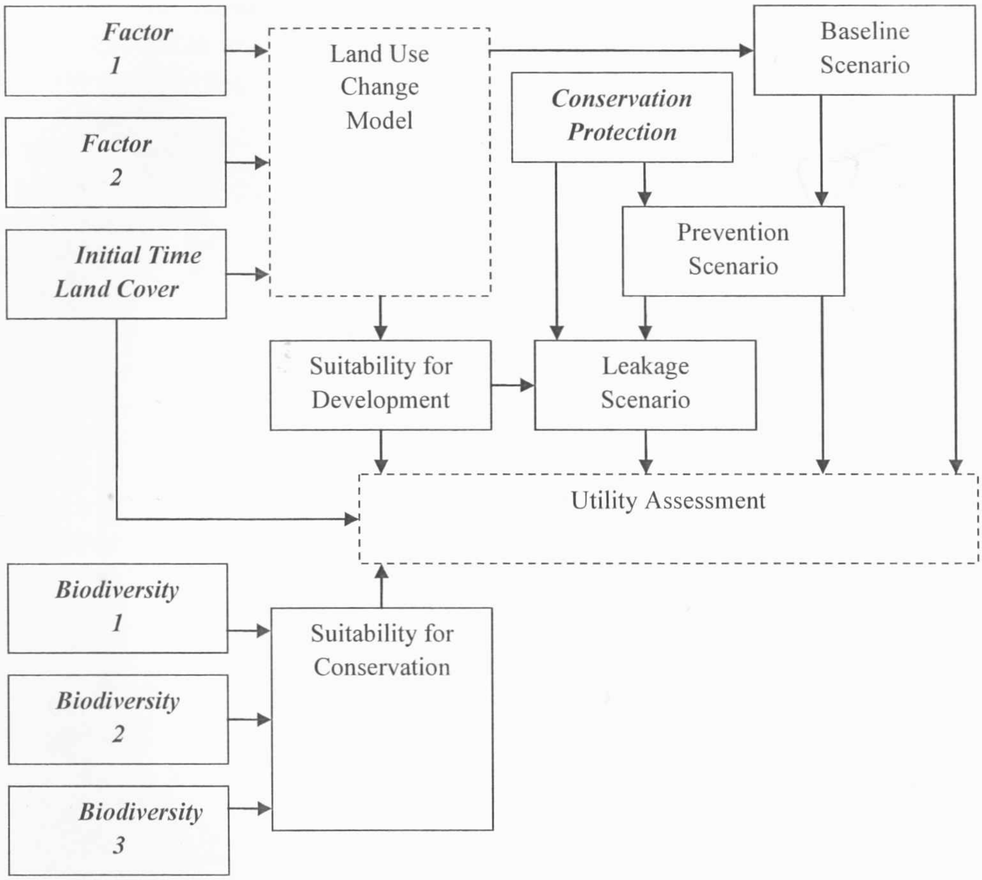

Figure 3. Flow of information in the analysis. Solid rectangles represent maps and bold italics specify input maps. Dashed rectangles indicate analytical procedures that are not maps.

This baseline scenario map is then overlaid with the map of protected areas to produce a map called the prevention scenario. The prevention scenario portrays the case where the protected status is perfectly effective at preventing the new clearing in the baseline scenario at those locations that are protected. This prevention scenario is shown in 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. Alas, we suspect that the protection status would not simply eliminate future development, since the effect of the protection is likely to displace future development from protected locations to unprotected locations, through a process of 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 quantity of newly cleared pixels, but some of the pixels are in different locations due to leakage. Figure 6 shows these shifts in spatial allocation that are associated with leakage.

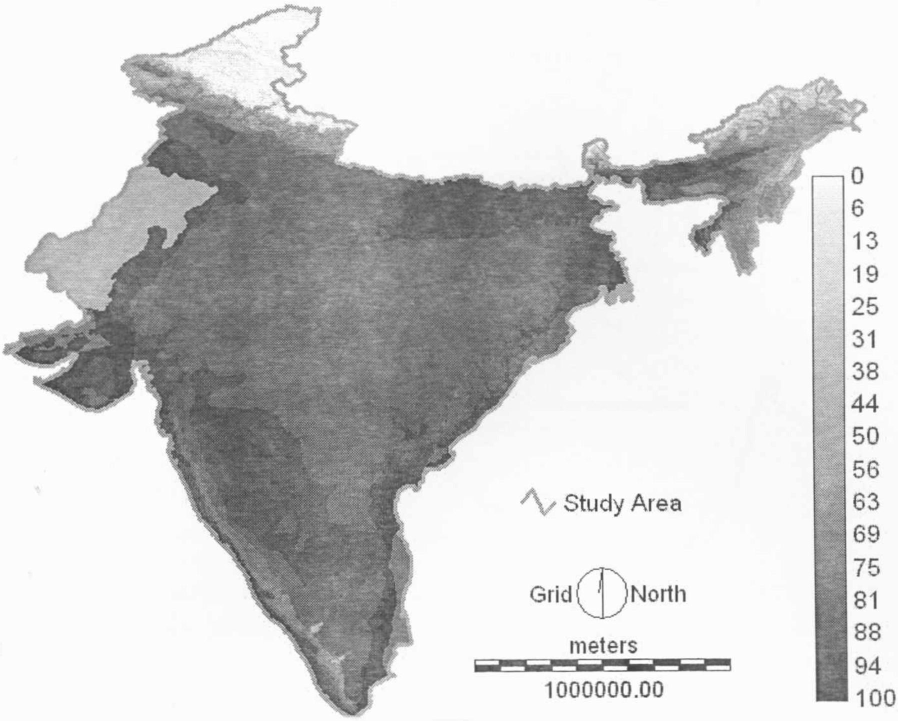

Figure 4. Suitability for development.

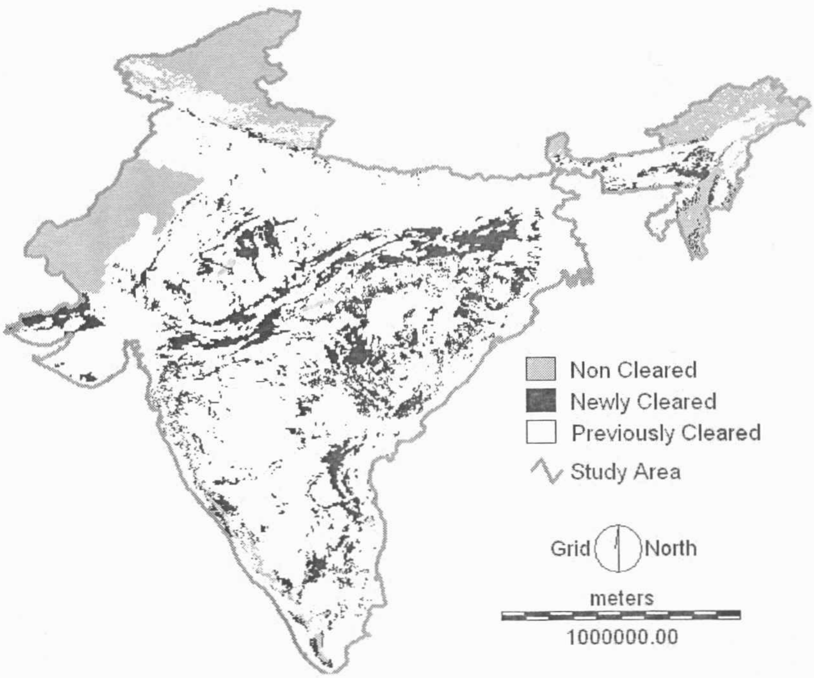

Figure 5. Baseline scenario where future clearing occurs at locations of high suitability for development regardless of protected status.

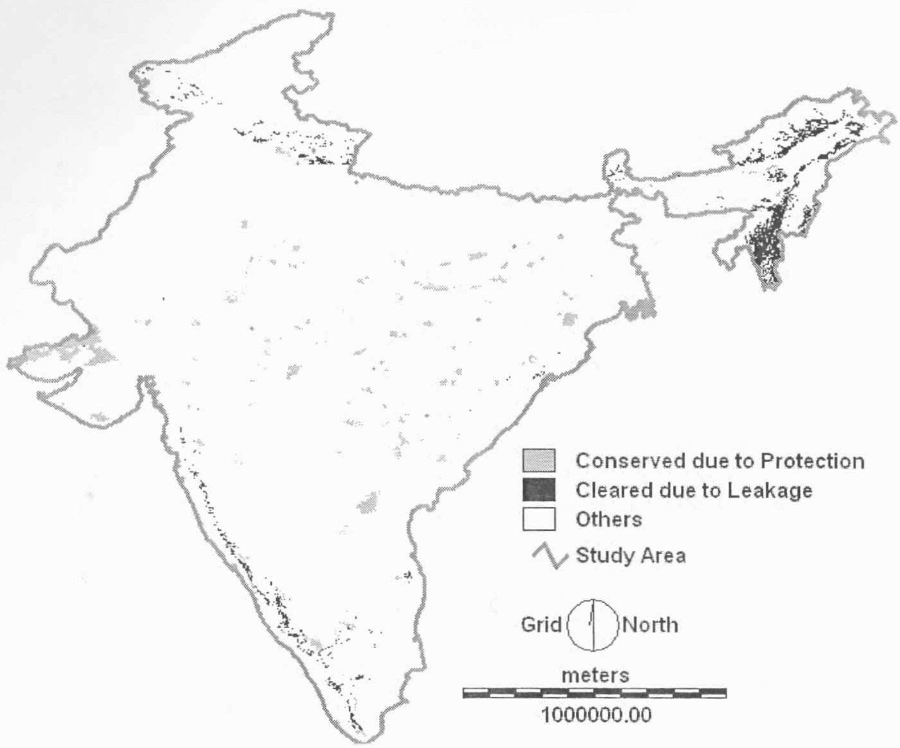

Figure 6. Effects of conservation and leakage where baseline clearing inside protected areas (gray) is displaced to locations outside protected areas (black)

If these shifts in spatial allocation cause 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 quantity of area of new clearing. However, if this shift in location causes the newly cleared pixels to move from locations of lower 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 each of the four land cover maps, i.e. the initial time and the three future scenarios.

Figure 7 gives the theoretical framework to quantify the information in the four land cover maps. The vertical axis shows the utility for conservation, which is conceptualized as the value of the ecosystem services that derive from the non-cleared areas; it 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 conceptualized as the value of the economic services that derive from the cleared areas; it 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 Figure 7 and the maps of the three future scenarios at the arrow heads below and to the right of the initial dot. These points are important in their position relative to each other, and not necessarily in terms of particular numbers along the axes for this particular application.

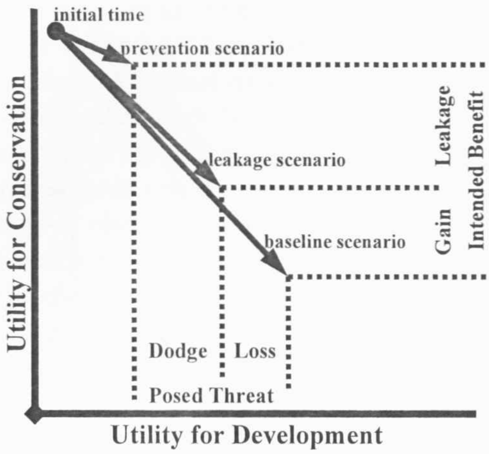

Figure7. Theoretical intended arrangement of points

It is helpful to describe each of the points in sequence. The point of the initial time shows the overall utility of the initial landscape in terms of both conservation and development. 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 7 shows the baseline scenario as lowest on the utility for conservation axis because it envisions that the baseline clearing occurs on land parcels that have relatively high values of utility for conservation. Figure 7 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 quantity of newly cleared pixels in the leakage scenario is identical to the quantity in the baseline scenario but the spatial allocation of those cleared pixels is different, therefore the positions of the points in Figure 7 are different. Figure 7 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 in 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 from the prevention scenario. 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 from the baseline. If the leakage scenario point is above the baseline scenario, then the overall effect is positive, as portrayed as "gain" in Figure 7. Figure 7 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 initially projected threat to utility for development. This shifting activity allows them to "dodge" the initial threat posed by the conservation project. To generate the leakage scenario, they shift their new clearing to their next 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 in terms of loss in utility for development from the baseline. Figure 7 expresses the loss in utility for development from the baseline as the posed threat minus the dodge.

Results

The results of our modeling application to biodiversity 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 6 shows how the leakage causes clearing to move from locations scattered about the subcontinent to locations clustered in three regions that Figure 2 shows as having very high suitability for conservation: Western Ghats, Western Himalaya, and Northeast India. Consequently, the resulting arrangement of points in Figure 8 is not consistent with the theoretical intended arrangement of points shown in Figure 7. Figure 8 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 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.

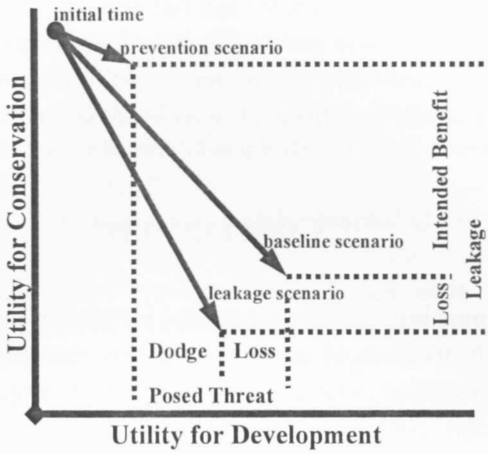

Figure8. Observed arrangement of points for the biodiversity case study where the only point that is different from Figure 7 is the leakage scenario point.

DISCUSSION

In our case study, we measured utility for conservation and utility for development as the sum of indices in pixels. This approach is somewhat simplistic, since it equates indices with utilities and assumes that the utility of the entire landscape is the sum of the indices within individual pixels. Future research should further develop these concepts in the context of specific applications. For example, if the concepts of this chapter are to be used to compute credits for offset trading, then the utility for conservation must be converted to monetary units. This is necessary for carbon dioxide offset projects that are designed to Reduce Emissions due to Deforestation and forest Degradation (REDD). For REDD projects, the suitability for conservation map would be a map of potential carbon emissions, where the utility for conservation in each pixel would be the mass of carbon dioxide emission equivalent that would be emitted from that pixel if it were to be cleared. For this case, the total amount of carbon emissions in the study extent is the sum of the carbon emissions from each pixel in the study extent. Pricing mechanisms have been designed to translate units of carbon into monetary units, so that offset credits could be awarded and traded. If both axes of Figure 7 have the same units, it may be reasonable to compare the cost and benefit tradeoffs between utility for conservation and utility for development.

It can be more challenging to specify the units for conservation 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. If two pixels contain very high levels of biodiversity of the same species, then the elimination of one of those pixels does not necessarily cause the elimination of the entire species, if the other pixel is protected effectively and the species uses a spatial range that is smaller than the size of an individual pixel. However, if the species demands a range that is larger than the size of an individual pixel, then the development of one pixel can cause species loss in neighboring pixels, even when neighboring pixels are protected. In this manner, biodiversity can be influenced by the spatial pattern of development, for example by whether large patches become fragmented, and not only by whether a particular location is developed. In many situations, there are various simultaneous goals for conservation, such as both carbon maintenance and biodiversity protection (Hardner *et al.*, 2000; Hecht and Orlando, 1998). In these cases, the situation is even more complex.

CONCLUSIONS

This paper offers some bricks in the conceptual foundation for using GIS and land change modeling to assess effectiveness of conservation. Our example of biodiversity protection illustrates how a conservation strategy to prevent developers from pursuing their first priorities can back fire and cause a lose-lose situation for both developers and conservationists when one considers the possible effect of leakage. 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. However, a policy of protection at only the locations with large conservation values may leave unprotected the locations where there is the largest immediate threat posed by development.

It is quite challenging to quantify the effectiveness of conservation projects because there are enormous philosophical and technological challenges to produce accurate baseline scenarios and to track leakage. Scientists should dedicate energy to address these challenges, because scientists are being asked increasingly to use GIS and land change modeling to advise land policy in order to address some of the planet's most pressing economic and environmental crises. It is necessary to measure the effectiveness of conservation in the manner outlined in this paper in order to implement international agreements for offset credit trading of ecosystem services. The earth's natural ecosystem services are already disappearing rapidly, so we urgently need to make progress on these issues in a process of learning by doing, because if we delay conservation until all these challenges are completely resolved, it will be too late.

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QUESTION BANK

True Or False

1. The baseline scenario is designed to portray a future in the absence of a conservation project.

2. The prevention scenario is designed to portray a future where a conservation project is successful at completely preventing the additional disturbance that the baseline scenario portrays.
3. The leakage scenario is designed to portray a future in which there are no conservation projects.
4. Leakage is the process whereby conservation at one location causes development to shift from that location to another location.
5. When there is zero leakage, then conservation efforts that were intended to prevent development will backfire, resulting in less utility of conservation than in the baseline scenario.
6. The suitability for development values of the pixels always indicate the monetary value that the developers could obtain if the locations at those pixels were to be developed.
7. The utility of development for any scenario's map is computed as the sum of suitability for development values of the pixels that are cleared in that scenario's map.
8. The utility of conservation for any scenario's map is computed as the sum of suitability for conservation values of the pixels that are not cleared in that scenario's map.
9. Kyoto Protocol on climate change and the subsequent Bali Roadmap call for conservation of land that has the largest density of carbon storage.
10. Land change models that simulate future anthropogenic disturbance predict a quantity of future development and then allocate the future development randomly in space.
11. There is evidence that land change models predict accurately because validation exercises show that most models produce more correctly predicted change than error at a fine spatial resolution.
12. For leakage analysis, selection of the extent of the study area has negligible influence on the results.
13. This chapter's map of protected areas in the Indian subcontinent show that the protected areas are not on the pixels that have the largest values in this chapter's map of suitability for conservation.
14. This chapter shows that the network of protected areas in the Indian subcontinent has been poorly designed.
15. This chapter shows how the present network of protected areas in the Indian subcontinent could backfire in terms of biodiversity protection if the network causes development to shift via a process of leakage from locations of lower biodiversity to locations of higher biodiversity.
16. This chapter tests how sensitive the results are to the accuracy of the land change model and finds that its conclusions are robust.
17. Geomod simulates both the transition from non-cleared to cleared due to development, and the reverse transition from cleared to non-cleared due to vegetation regrowth on abandoned land.
18. This chapter shows that it is possible to have a lose-lose situation where developers are denied their top priorities thus clear the land that has higher suitability for conservation.

19. This chapter describes how the quality of the input maps has been assessed and concludes that the maps are sufficiently accurate.
20. The foundations concerning the theory and practice of how to assess the effectiveness of conservation are sufficiently developed so that the only remaining challenge is to obtain high quality maps to perform the analysis.

Short Answer Questions

1. The intended benefit of a conservation project in terms of utility for conservation is the difference between which two scenarios?
2. For what types of conservation applications does it make most sense to compute the total utility of conservation as the sum of the individual pixel values of suitability for conservation?
3. For what types of applications does it make least sense to compute the total utility of conservation as the sum of the individual pixel values of suitability for conservation?
4. The concept of dodge in terms of utility of development is analogous to what concept in terms of utility of conservation?
5. How was the suitability for conservation map created in this chapter?
6. How was the suitability for development map created in this chapter?
7. What are the most important aspects of the relative positions of the points in figures 6 and 7?
8. What are the advantages and disadvantages of following a strategy to protect the locations that have the largest suitability for conservation, regardless of the threat posed by development?
9. What are the advantages and disadvantages of following a strategy to protect the locations that have the largest threat posed by development, regardless of suitability for conservation?
10. How can a conservation project that is intended to preserve ecosystems cause a lose-lose situation for both conservationists and developers?

Long Answer Questions

1. Describe the range of applications in natural resources management for which the principles of this paper could be applied.
2. Describe the types of analysis that would be necessary to express both utility of development and utility of conservation in the same monetary units in order to examine the tradeoffs between development and conservation.
3. Describe how the extent of the study area can influence the results of the analysis of effectiveness.
4. Describe the likely strategies that a developer would use to circumvent a conservationists plan to prevent development.

5. Describe the processes by which decisions are made in practice concerning where to locate protected areas and how the methods of this chapter could influence those processes.