INTEGRATING THE BIODIVERSITY MANAGEMENT AREA SELECTION MODEL INTO A MULTI-USE FOREST PROGRAMMING MODEL: THE CASE OF RELMDSS

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ABSTRACT.—Forest management has evolved from a multiuse perspective to include both natural resource and ecosystem management. Ecosystem management involves the protection and enhancement of natural environments with the long-term objective of ensuring biodiversity. This paper describes a model that has been developed to help select areas in a forested region that should be managed to enhance the long-term level of biodiversity. Such a model can be integrated with a multi-use forest planning model within a spatial decision support system to provide forest planners and analysts the capability of determining the tradeoffs between biodiversity management goals and traditional forest management objectives.

INTRODUCTION

For many governmental agencies in the United States including the USDI Bureau of Land Management and the USDA Forest Service, forest management over the past fifty years has evolved from a simple, single objective timber resource problem to a more complex multi-use management problem. With the recognition that some species are at risk of extinction, the Endangered Species Act further changed the character of forest management. In addition the National Environmental Protection Act (NEPA) made it mandatory that environmental impacts be assessed in major governmental operations. Consequently, the problems of forest management have become increasingly more complex and difficult to assess. It is easy to see that in many regions of the Forest Service, much of the time and effort spent in determining management options involves environmental impact assessment, mitigation, and analysis. The largest and most costly study performed in region 5 of the Forest Service in recent history involved two independent studies of the Sierra Nevada region within the context of the long term survival of the spotted owl and other threatened or endangered species. In the Pacific Northwest, considerable time and effort has been spent in addressing forest operations and the impact on such species as the spotted owl and steelhead trout.

Addressing major environmental impacts on a regional basis has changed the character of institutional approaches for analysis. For example in the Pacific Northwest, the now famous study on the spotted owl was developed by a team of scientists and forest analysts who were brought together from a variety of positions and areas: university, forest planners, and forest researchers. Such regional studies cut across a number of National Forests as well as other governmental managed land units like the Bureau of Land Management. Dippon (1997) presents an example of cooperative forest management planning involving the BLM and the Forest Service where both agencies are managing land in the same watershed. Such cooperative and regional studies will become more common, as the distribution and habitat of threatened species must not be analyzed forest by forest but on a larger regional scale.

At issue is the need to identify those lands that can be effectively used to ensure the continued presence of species that are either threatened or have been dwindling in numbers. Management alternatives for such critical areas

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might involve wilderness protection, the elimination of grazing, reduced forest operations or a combination of one or more management actions. In some areas, increased activities may help in long term viability. Such activities clearly fit within a context of operating to meet or exceed a desired future condition. The objective of this paper is to present a model which was developed as a part of the Sierra Nevada Ecosystem Project (SNEP). This model is called the Biodiversity Management Area Selection model (BMAS). It can be used to identify the most effective areas for maintaining a minimum range or distribution of species or biological elements that are threatened. The basic premise is that it is important to identify those land units that can be effective in planning for and maintaining biodiversity as a part of overall forest management. Given that such areas are identified, then it is necessary to integrate this need and the potential into overall forest planning. Such an analysis may be performed at the regional scale, or at the forest scale given targets that have been defined for the region and dissaggregated for the individual forest. The remainder of this paper describes the BMAS model and the present plan to integrate the model into the RELMdss (Regional Ecosystem and Land Management Decision Support System).

OVERVIEW OF THE BMAS STRATEGY

There have been several approaches that have been developed for identifying land units which should be reserved for the purpose of biodiversity protection. Such approaches fall into principally two categories: 1) reserve design and 2) site selection, Reserve design models involve the selection of land parcels which in total yield a contiguous area of land which has 1) a large enough size that it maintains a viable habitat for one or more species, 2) it is as compact as possible and involves a low perimeter to area ratio, 3) includes sufficient habitat of a suitable quality for the species of interest. Reserve site selection involves the selection of independent parcels which together, combine a sufficient level of land and biota protection which: 1) represents as many species as possible, 2) represents those species which are considered endangered. It is assumed that sites are of viable sizes. The units are usually selected independent of arrangement. Often reserve design models are meant to delineate the best site crafted from a set of prospective parcels whereas reserve site selection models involve selecting from a wide variety of sites a collection of sites which together meets a number of regional targets for representativeness and distribution.

As the landscape of natural areas becomes more fragmented by land use conversion from natural to agricultural, urban, recreation, or other, the viability of certain species may be threatened. Unfortunately, the exact habitat response and potential for viability is not well understood for most species. Just what is required for the long run viability of a given plant or animal is often not known. Even though we might not know exactly what is needed for a given species, there are two ways that we can approach this problem with some certainty that protection will be afforded. First, threatened species do need to be represented in reserve areas. Second, the more area that involves a given species, the better. Third, connectedness is usually good, involving wider pools of genetic diversity for a given range of animals and plants. Third, it is important to concentrate scientific efforts on understanding those sentinel species which can be used as indicators of overall heath and viability.

The approach taken in the development of the BMAS model involves the first two types of objectives. First, areas selected for enhanced biodiversity management or protection should represent those species which are threatened or where the amount of viable habitat is decreasing. Second, the BMAS model involves selecting at least a minimum amount of habitat or species range, for a given threatened species or element. Since a large region of the Sierra Nevada is managed for renewable resources, like grazing, timber harvesting, and recreation including hunting and fishing, much of the region falls outside of the category of intense land use. Consequently, it seems reasonable that connectedness is in part provided by the fact that selected biodiversity management areas will fall within a matrix of large government and private tracts of land managed for renewable resources. The threat to habitat destruction and fragmentation and their impact on species viability is based in part on land use conversion to more intense activities, like residential subdivisions or by activities like increased road building, etc., and incompatible land uses like grazing in a sensitive riparian zone. The idea is that because many areas of the Sierra Nevada are managed as a part of a large renewable resource industry, areas selected for biodiversity can act as protected or managed areas that insure the presence of species across the Sierras. Areas managed for natural resources may not necessarily preclude such viability in and of itself. Such BMA areas would serve as the source of and species viability at a level of higher protection or management. Thus, a Sierra BMA system would not function

as an archipelago of biological reserves, but as a “core area” of higher quality for many species and/or sanctuaries for species and habitat types that are negatively impacted by human activities.

The basic strategy involved by the BMAS model is to select panning units for more intense management with the purpose of promoting biodiversity protection. This is accomplished by first identifying those species or habitats that are threatened and then determining the needed area to represent such species with at least a minimum level of protection. Then, the most efficient set of areas is selected which are needed to provide at least the minimum level of area distribution for each threatened species. The final step is accomplished by the solution of the BMAS model.

A MODEL FOR SELECTING BIODIVERSITY MANAGEMENT AREAS

The major objective is to represent the distribution of species or biodiversity elements which are at risk in a core of biodiversity management areas to help provide for long term viability. Each biodiversity management area would be managed to enhance such elements that are considered at risk or are threatened. Management might mean simple prescriptions like eliminating grazing from riparian areas to substantial intervention in order to protect a special habitat. The major issue is to represent so called elements at risk by selecting enough management units that contain such elements that the total area of each element within the selected units meets some desired minimum standard. In order to apply a BMAS approach, it is necessary to have a database that reflects current land cover, habitat distribution, and species presence. Further, it is desirable to characterize as fully as possible human activities, especially roads, land use zoning, population, industry, employment, etc. With such data, it is possible to forecast both land use and activities for a region. The ultimate objective of such a forecast would be to estimate land use changes. Such changes in land use can be used to identify the reduction in habitats that support various species. Thus, we can determine the extent to which various species, communities, endemic plants, old growth stands, etc. are at risk now or in the future. Any plant, animal, habitat, or community at risk will be called an element. We can think of elements at risk as being vulnerable as long as forecasted change is allowed to occur without some type of intervention or protection.

In order to apply the BMAS model it is necessary to define a basic decision making unit. Such a unit should be land based: large enough to make sense, but small enough that flexibility is afforded. For the application of the BMAS model in the Sierra Nevada region, the land units were the watersheds defined by the California Department of Forestry and Fire Protection. For the Sierra Nevada range there are approximately 2700 watersheds. The average watershed size is about 3000 ha (or 7,000 ac.). Watersheds make logical planning units for they are easily located on the ground, are appropriate physiographic units for managing ecosystem and hydrologic processes, and may be large enough to support viable populations of many plant and animal species. The areal extent of every plant community type was calculated by intersecting the watershed boundaries with a map of plant community types (Davis and Stoms, 1995). The vegetation map was prepared at a 1:100,000 scale for the gap analysis study of the Sierra Nevada. On the average, there are several plant community types for each watershed. Data was also collected on land use, population, roads, etc. for each watershed.

By forecasting land use conversion and increased activities, the loss of habitat for each species was calculated. Given such losses, species and communities were identified as being threatened. In order to protect an element at risk, it was determined that a certain fraction of existing distribution should be protected or maintained. If forecasted land use changes meant that an element would no longer be represented at least at the minimum fraction of existing distribution, then that element was defined to be at risk. The area needed to raise the element from being at risk was defined as that amount of area that would be necessary to ensure that the existing habitat area was greater than the desired minimum fraction. Therefore, from forecasted land use and maps of existing vegetation and species distribution, it was determined which elements were at risk and how much protected area was necessary to keep the element from being at risk. We recognize that the minimum fraction used in the study was somewhat arbitrary (15 and 25 percent), and it is necessary to determine appropriate minimum fractions for each element.

BMAS Model and Notation

The BMAS model involves the selection of land units that can help provide needed core habitat among a matrix of land being managed for renewable resources. It has been expressively developed for those cases where there is significant land being devoted to primary industries such as timber harvesting and grazing. The model helps select those areas that would be most useful in maintaining a minimum distribution of specific elements that are determined to be at risk. In order to define the BMAS model mathematically, we need to introduce the following notation:

k,K = index and set of elements at risk

j,J = index and set of planning units

Min_k = minimum area containing element k that is needed under BMA distinction

Hd_j = human density of planning unit j

PPI_j = the density of public-private land interface in unit j

Pla_j = percentage of area in private ownership for unit j

a_j = the are of planning unit j

r_j = percentage of the area in planning unit j which is impacted by roads

a_{jk} = area of planning unit j which contains element k

w_l = weight attached to term l in the objective

$$X_j = \begin{cases} 1, \text{ if watershed unit } j \text{ is selected for a BMA} \\ 0, \text{ if not} \end{cases}$$

The BMAS model can now be formulated as:

Minimize Z= $\sum_j \left(w_1 a_j + w_2 Hd_j + w_3 r_j + w_4 Pla_j + w_5 PPI_j \right) X_j$

Subject to:

1) Ensure that element k is no longer in jeopardy

$$\sum_j a_{jk} X_j \geq Min_k \text{ for each } k \in K$$

2) Integer requirements

$$X_j = 0,1 \text{ for each } j \in J$$

The above formulation is deceptively simple. Each of the constraints represents a lower bound on what must be included among the chosen watersheds in terms of a given element. The objective minimizes a combination of a number of factors, each assigned a penalty weight. The first term is associated with minimizing the area of all chosen watersheds. The smaller the total area chosen for biodiversity management, the lower overall costs will be, including monitoring. The second term minimizes the choice of watersheds with high population. Thus, watersheds with lower population densities will be preferred. The third term discourages the choice of watersheds with a high level of road density. Road density represents the length of all roads divided by the total area of the watershed. The larger road density is the more likely is the level of access and potential fragmentation. Thus, this

third term encourages the choices towards areas that are less accessible and potentially less fragmented. The fourth term of the objective discourages the choice of watersheds that have a larger percentage of private ownership. The basic premise for this objective term is that the greater the level of public ownership in a given watershed, the easier it will be to declare and manage an area with biodiversity management being the primary objective. The fifth term of the objective discourages watersheds from being chosen that have a large level of public-land private-land interface. The greater the amount of interface between public and privately owned lands the higher the level of fragmentation and the greater the level of private ownership. The greater such levels are, the less likely such an area is either natural or easy to manage for biodiversity enhancement. In total, the objective tends to encourage the selection whenever possible of those watersheds that are publicly owned, have few people, and are less developed in terms of roads. For application solely with a National Forest or a group of Forests, planning units may involve land that lies solely within the National Forest or potentially other areas as well. This would depend on the application. For the Sierra Nevada study, all watersheds were considered. For some areas it may be possible to demonstrate that certain biodiversity elements cannot be protected at all on public lands.

Even though the model is quite simple in structure, the BMAS formulation given above can be quite difficult to solve. This is due to the integer restrictions on the decision variables, where a watershed is either chosen or it isn't. In fact the formulation can not be classified as integer friendly. However, techniques have been developed to tighten this formulation and make it easier to solve using linear programming with branch and bound (Church et al. 1997b). Heuristics have also been developed to solve the BMAS problem and have proven to be effective at solving relatively large BMAS problems. This is a subject of a recent research paper (Okin 1997). Results of the BMAS applied to the Sierra Nevada region are presented in the second volume of the SNEP report to Congress (Davis 1997).

INTEGRATING THE BMAS MODEL INTO RELMDSS

One of the major elements missing from existing forest modeling systems such as SPECTRUM is a clearly defined methodology for handling issues of biodiversity protection and enhancement along with the more typical multiuse goals. Although it is possible to establish a target or goal for lands to be designated as a biodiversity option, it is not an entirely simple task given that it requires a discrete choice variable (i.e. integer variable). This is a factor that complicates the coordinated allocation of choices style of model originally developed in FORPLAN. Unfortunately, models like BMAS are not easy to solve and can easily tax a general purpose linear programming/integer programming software system. Special heuristics are necessary in many instances, and thus a system which allows for solution methodologies other than general purpose LP/IP is needed. It is desirable to integrate models like BMAS into strategic and tactical level planning models so that forest analysts can easily address the goals of ecosystem management. It is important to be able to solve for the tradeoff between desired levels of protection and harvesting. It is also necessary to track the potential impacts on dwindling habitats as strategic and tactical decisions are being made.

As a first step towards integrating the BMAS model into strategic and tactical level forest planning models, we have chosen to integrate the BMAS model into the RELMdss. The RELMdss model is a decision support system that is designed to be applied at both the tactical and strategic levels (Church et al 1997a). Its development has been supported by the Forest Service in order to track and resolve constraints involving standards and guideline conditions at a higher level of spatial resolution than typically used in such models as SPECTRUM. It also contains a user interface which allows the analyst to visually inspect flexibility across planning units. Unfortunately, the structure of the BMAS model does not easily fit within the five models currently defined in RELMdss. In order to integrate the BMAS model into RELMdss, it is necessary to first expand the definition of one of the main RELM models so that both data input and model structure can encompass the BMAS problem as well. Such a model and data input expansion is currently under development. In addition, both integer programming and heuristic techniques will be needed in order to provide the capabilities to solve such a model over a range of sizes. The development plan is to add the capability to RELMdss so that a series of models can be solved sequentially on the same area, where the results of one model are fed into the next model. As an example, let's assume that we first solve a BMAS model in order to identify a set of planning units to set aside for biodiversity management. Such a

designation would not necessarily preclude all harvesting activities, but it may mean additional limits on thresholds established for specific standards and guidelines (in order to classify the area as BMA). Then, such changes or BMA designations are made or fixed into the RELM model data. The analyst could follow the BMAS analysis by the solution of a classical RELMdss model like the MIN_AREA model. This model can be used to translate harvest targets and other activities to planning units in a manner which is then compatible with the BMA designations. Thus, biodiversity management goals can be directly integrated into the strategic or tactical level model. This allows the analyst to determine a plan which best fits the BMAS solution. The interface for the RELMdss will also be expanded in order to allow the analyst to easily change BMA designations and then resolve a model. The system will allow the analyst to reselect BMA units (designate a new BMA, eliminate an existing BMA designated unit, and track BMA element protection targets). Subsequent solution of the MIN_AREA model would then allow the analyst to check the impact of the new designations on the overall performance of the targets and goals. By giving the analyst to quickly change area designations, various spatial options can be explored and tradeoffs between levels of harvesting and BMA protection can be explored. Thus, we propose to integrate the Biodiversity planning elements with the more common multiuse management components in order to provide a flexible decision support system that can aid in ecosystem management.

SUMMARY

The purpose of the paper has been to present some of the details of the biodiversity management area selection model (BMAS). This model has been developed to help identify potential areas within a forested region that could be used to enhance or protect biodiversity. In order to solve for both biodiversity goals and more traditional multiuse goals, a flexible modeling approach is outlined which involves the BMAS model and the decision support system called RELMdss. Changes are underway to support the solution of BMAS model within the RELMdss system along with the capability of solving sequentially several models, both BMAS and RELMdss models. This will allow the analyst to feed results from one model as inputs into another model. This approach will make it possible for the analyst to easily explore possible options and tradeoffs between biodiversity management goals and more traditional multiuse goals.

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