Conserving biodiversity by conserving land

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July 2002

Introduction

Land management decisions on public and private lands affect important ecosystem processes and functions with potentially far-reaching and long-term consequences. Humans are now managers of much of the habitable land of the earth. Over half of all land that is not tundra, ice, boreal, desert, or rock is devoted to agriculture (Tilman et al. 2001). Including managed forests, the majority of habitable land on earth is actively managed for human uses. The expected increase of 2 to 3 billion people over the next 50 years will further increase human land use needs.

In a recent book, biologist Simon Levin states: "the central environmental challenge or our time is embodied in the staggering loss, both recent and projected, of biological diversity…" (Levin, 1999). Though other factors, such as the introduction of exotic species, over-harvesting, pollution and climate change, contribute to the loss of biodiversity, habitat loss is thought to be the primary reason for loss of terrestrial biodiversity (Ehrlich and Ehrlich 1981, Wilson 1988). In fact, a common method biologists use to predict the number of species present in a given land area is through construction of a "species-area curve," which is based on empirical evidence linking the amount of habitat and the number of species found in the habitat (MacArthur and Wilson 1967). Several studies have found that the current rate of species extinction is several orders of magnitude above the "natural" or background rate of extinction (National Research Council 1995, Pimm et al. 1995). Given land conversion trends, projections into the future are for even higher extinction rates (Wilson 1988).

In the U.S., the Endangered Species Act has focused attention on the relationship between land use and species conservation. Under the Endangered Species Act,

otherwise lawful land uses may be prohibited if they would result in harm to a species listed as endangered or threatened. Included in activities that cause harm are land uses that significantly modify habitat in ways that kill or injure listed species or interfere with essential activities such as breeding, feeding or sheltering. A number of recent high profile endangered species cases have highlighted actual and potential restrictions on various land uses, including timber harvesting and urban development. These cases include timber harvest restrictions to protect the spotted owl and marbelled murralet in the Pacific Northwest, potentially wide-ranging restrictions on urban and rural land use to protect salmon from Washington to California, restrictions on land development in Southern California to protect the California gnatcatcher, Stephens Kangaroo Rat and other species, and timber harvest restrictions in the Southeast to protect the red-cockaded woodpecker.

As the Endangered Species Act examples demonstrate, society faces difficult choices over whether to allow habitat conversion for economic gain versus conserving habitat to protect biodiversity. In each of the cases mentioned above, there is a tradeoff between economic activity (timber harvest, housing development, etc.) and conserving habitat of threatened and endangered species on certain lands. Because the conservation of biodiversity and the material well being of the human population are both important goals, it is important to set conservation priorities intelligently and minimize the reduction in other goals from pursuing conservation. In this chapter, our objective is to ensure that the maximum amount of biodiversity is conserved for any given level of cost. We illustrate our approach to this problem using land value data, taxonomic and geographical distribution data for breeding bird species in Oregon.

In the next section, we present a general framework for cost-effective conservation decision-making that was first described in Solow et al. (1993). The framework requires specifying a biodiversity measure as an indicator of the relative worth of possible conservation outcomes, the probabilities of various outcomes occurring under a given set of management actions, the cost of these management actions and the conservation budget. We then discuss in more depth biodiversity measures and management actions. We apply our framework to a practical problem of selecting biological reserves under a budget constraint to maximize two measures of species diversity using taxonomic information, geographical distribution data of bird species and land values in Oregon. The final section contains concluding comments.

A Conservation Decision-making Framework

We begin by explaining the conservation decision-making framework of Solow et al. (1993). In this framework, the goal is to maximize expected biodiversity conserved under a budget constraint. There are three important components to this framework. First, what is the definition of biodiversity? In other words, what is the objective of conservation? For example, the definition of biodiversity could be the total number of species conserved or it could be a measure of the value of ecosystem services provided. In order to proceed with the analysis, however, there must be a clearly defined objective. In the applications that follow we will use two different biodiversity measures based on presence or absence of species: i) the total number of species present (species richness), and ii) a measure of phylogenetic diversity of the conserved species.

Second, how do various management actions affect biodiversity? A wide range of management actions can be considered in this framework. Management actions could include such things as setting aside habitat as biological reserves, alternative pesticide application or tillage practices on agricultural land, or alternative timber harvest rotations in forests. Management actions could also include consideration of public policies such as zoning laws that restrict allowable land uses on certain parcels, or decisions on where to put infrastructure, such as roads or sewers, which will affect the pattern of future development activities. Since habitat decline is probably the single most important cause of biodiversity decline, land use and land management decisions are particularly important to analyze. In the application to follow we will focus on the conservation strategy of setting aside land for biological reserves. Once it is decided what management actions to consider, there must be some way to assess the biological consequences of implementing those management actions. In practice, there may be limited ecological knowledge on which to base this assessment. At present, lack of ecological understanding is a key limiting factor in our ability to make intelligent choices regarding conservation. In the reserve site selection problem we will consider, the typical assumptions made are that species that are represented in those land areas selected in reserves will be conserved while those outside of any reserve area will be lost.

Third, what are the costs of various management actions? At a very general level, these costs represent sacrifices in other goals that must be made in order to further conservation. In the application to follow we will measure these costs in dollar terms. For example, if a public land management agency decides to prohibit timber harvesting or grazing on public land in order to protect habitat for certain species, the cost of this

restriction would be the foregone income that could have been earned had timber harvesting or grazing been allowed. It is important to note that these costs are what economists would call opportunity costs in that it represents the cost of foregone opportunities to society required for conservation. Opportunity costs are not necessarily the same thing as the budgetary consequences for an agency or landowner. Prohibiting logging in order to protect an endangered species may not require any budgetary outlay but it does impose an opportunity cost in terms of lost income from timber operations.

Formally, the conservation decision-making problem combining these three elements can be written as:

$$\text{Max} \sum_{s \in S} D(s) P_x(s)$$
$$\text{s.t.} \ \ C(x) \le B \tag{1}$$

where $D(s)$ is the measure of biological diversity of outcome $s \in S$, S is the set of possible outcomes, $P_x(s)$ is the probability that outcome s will occur under conservation strategy x that describes what management actions will be taken, $C(x)$ is the opportunity cost of implementing conservation strategy x, and B is the conservation budget. By varying the budget, one can trace out the maximum achievable level of biodiversity conservation for various budget levels. In other words, following this procedure one can establish the cost curve for biodiversity conservation.

Before turning to the application, we discuss in more detail biodiversity measures, specifically focusing on measures based on species presence and absence, and management actions, specifically focusing on the reserve site selection problem.

Biodiversity Measures: Species Richness and Phylogenetic Diversity

What is referred to as "biodiversity" can mean many different things. For example, one heavily referenced definition of biodiversity is the following:

> "Biodiversity is the variety of life and its processes. It includes the variety of living organisms, the genetic differences among them, the communities and ecosystems in which they occur, and the ecological and evolutionary processes that keep them functioning, and yet ever changing." (Keystone Center 1991)

Virtually anything in the field of study of biological sciences can fit into this definition. It is important to have a clear statement of the objective for any optimization or priority setting exercise. For purposes of concreteness in what follows, we focus on measures of diversity that depend upon survival or extinction of species, which we will refer to as measures of species diversity. Prior work on measure of species diversity includes Faith (1992, 1994), Solow et al. (1993), Solow and Polasky (1994), Vane-Wright et al. (1991), Weitzman (1992, 1993). Of course, we do not intend to imply that these measures capture all of the importance or value of biodiversity.

The simplest measure of species diversity is species richness. For species richness, $D(s) = N$, where N is the number of surviving species in outcome s. Using species richness as the objective means that one implicitly assumes that all species have equal conservation value. Further, it implicitly assumes the value of conserving any individual species is independent of what other species survive or go extinct.

A measure of phylogenetic diversity takes account of the dissimilarity among species and gives higher value to species that are relatively unique among the set of surviving species. Phylogenetic diversity for a set of species is defined as the branch length of the phylogenetic tree for those species. A phylogenetic tree represents the pattern of evolution among species, indicating when species took divergent paths from a common ancestor. Assuming a constant rate of DNA changes along all branches, the branch length connecting any two species is proportional to the genetic dissimilarity between the species.   Conserving a species that does not have closely related surviving species adds more to phylogenetic diversity than conserving a species that does. In this sense, phylogenetic diversity places a premium on genetically unique species. Under phylogenetic diversity, the marginal value of a species is not constant but rather depends upon the phylogenetic distance to the nearest surviving species.

Figure 1 shows a simple example with four species. The measure of phylogenetic diversity for the set of all four species is the entire branch length of the phylogenetic tree shown in figure 1, or 14. If species A is lost but B, C and D remain, the measure drops to 13. However if both A and B are lost, then the whole left hand branch is lost and diversity falls to 8 (2 + 3 + 3). The marginal value of conserving species A, which is defined as the change in phylogenetic diversity when species A goes extinct, depends upon whether species B is conserved or not. If B is conserved then the marginal value of conserving A is only 1, because diversity declines from 14 to 13. If B is not conserved then the marginal value of A is 5, because the diversity of species A, C and D is 13 while that of C and D alone is 8. Under species richness, the marginal value of a species is constant regardless of what other species are conserved or extinct.

Measures of species diversity as described above are measured in biological terms. Another approach is to try to monetize the value of various biological outcomes. The advantage of doing so is that when *D(s)* is specified in dollar terms then the decision-making framework can be simplified to one of maximizing net benefits:

$$\text{Max} \sum_{s \in S} D(s)P_X(s) - C(x) \tag{2}$$

In economic terms, equation (2) represents a cost-benefit approach. In comparing across different sets of management actions, the preferred choice is one that results in the greatest difference between benefits and costs (i.e., maximum net benefits). On the other hand, equation (1) represents a cost-effectiveness approach. One cannot directly compare biological benefits with dollar value costs. Instead, the approach is to get the greatest biological return for any specified level of cost. A cost-effectiveness approach can be used to find the best strategy given a budget but cannot be used to find the optimal conservation budget. The cost-benefit approach can be used to find the optimal conservation strategy including the optimal size of the conservation budget.

Valuing conservation outcomes in dollar terms presents a number of daunting challenges. Much of the value of biodiversity conservation may be non-use or existence values. Survey methods are the only tools available for measuring such values. Even if the biology is totally understood, the multi-dimensional species or land valuation problem requires presenting a great deal of information to survey respondents. It is unlikely that survey respondents or researchers have the patience and ability to synthesize all the potentially relevant information. Klauer (2000) states that "people

cannot be expected to analyze the behavior of ecosystems when making economic decisions. Preferences of individuals do not reflect everything scientists find out about the functioning of ecosystems." An added complexity to this valuation problem is the uncertainty surrounding ecosystem changes and the temporal reliability of value estimates (Barbier 1994; Bingham et al. 1995; Bockstael et al. 1995; Suter 1995; Toman 1997). Bockstael et al. (1995) state: "By evaluating only those components of the ecosystem that have immediate values to individuals, and focusing on short term changes, this practice ignores the fact that changes in ecosystems play out over time and space and may indeed be irreversible." Besides the difficulties with incomplete information and the assimilation of information, many people find it difficult or fundamentally object to making tradeoffs between conservation and money (see, for example, Spash and Hanley 1995).

Because of the difficulty of estimating values in dollar terms, it is often easier and more defensible to work in terms of cost-effectiveness analysis rather than cost-benefit analysis when analyzing biodiversity conservation, as we shall do here. The valuation question, however, cannot be avoided entirely even when one sticks to biological measures. Trying to maximize a measure of species diversity may require value judgments about the relative worth of different species. Likewise, a measure of ecosystem function may require value judgments about the relative importance of different ecosystem functions.

Management Actions: The Reserve Site Selection Problem

As stated in the introduction, conserving biodiversity is largely a matter of conserving habitat. In other words, the most important management actions for conservation of biodiversity are largely land use decisions. One particularly simple format for considering land use decisions is the reserve site selection problem. In the reserve site selection problem, a conservation planner chooses a set of sites to select as biological reserves under a budget constraint to maximize a measure of biodiversity, in our case either species richness or phylogenetic diversity. Species that are present in at least one selected site are assumed to survive. Those species not present in any selected site are assumed to go extinct.

When species richness is the measure of biodiversity, the reserve network selection problem is an integer-programming problem and can be written formally as:

$$\max \sum_{i=1}^{m} y_i \qquad (3)$$

subject to :

$$\sum_{j \in N_i} x_j \geq y_i, \, i = 1, \, 2, ..., m \qquad (4)$$

$$\sum_{j=1}^{n} c_j x_j \leq B \qquad (5)$$

where $x_j = 1$ if site j is chosen, 0 if not, $j = 1, 2, \ldots, n$, $y_i = 1$ if species i is covered, 0 if not, $i = 1, 2, \ldots, m$, $N_i =$ the set of candidate sites that contain species i, $c_j > 0$ is the opportunity cost of choosing a reserve at location j and $B > 0$ is the conservation budget. The objective function (3) is to maximize the number of species included in the network.

The *m* constraints represented in (4) ensures that species *i* is not counted as included if no site in which it occurs is selected. The budget constraint is given in (5).

When the objective is phylogenetic diversity, the objective function in (3) is replaced by:

$$Max \ P(y_1, y_2, ..., y_m) \tag{6}$$

where $P(y_1, y_2, ..., y_m)$ is the measure of phylogenetic diversity given that the species that survive are those for which $y_i = 1$.

Integer-programming problems can be quite difficult to solve, especially if many sites can be chosen from a large number of potential sites. In other papers, we have used methods from operations research to solve for the optimal set of sites to maximize species richness under a budget constraint (Ando et al. 1998, Polasky et al. 2001a). These papers used species richness as the objective function. Maximizing phylogenetic diversity makes the integer programming problem much harder to solve. To date, the problem of maximizing phylogenetic diversity has not been solved optimally for large problems. In the application that follows, we follow the lead of Polasky et al. (2001b) who used the "greedy algorithm" to find a good, though not necessarily optimal, solution for this problem. In the greedy algorithm, the first site chosen is the site that has the largest diversity per dollar. For example, with species richness as the objective, the first site chosen would be the one with the highest ratio of number of species present to site cost (c_i). Beyond the first site, sites are added sequentially by choosing a site that adds

the greatest increment to the objective function per dollar spent. Sites are added in this fashion until the budget is exhausted.

The greedy algorithm has great intuitive appeal in that each site chosen gives the largest return per budget outlay of any site that could be added to existing sites. Though the greedy algorithm generally finds good solutions, it does not necessarily pick an optimal solution. A simple example illustrates this point. Suppose that only two sites may be protected out of three potential reserve sites (labeled A – C in Table 1). Species (labeled 1 – 6) inhabit various sites as shown in Table 1. The optimal choice in picking two sites to maximize species diversity is to choose sites B and C, which together cover all six species. However, the greedy algorithm begins by selecting site A since it contains four species while the other sites only contain three. At the second step, either site B or C would be added to A. Either way only five of the six species are covered.

Application: Conserving Bird Genera in Oregon

In this section we illustrate the application of the approach for selecting which sites to include in a biological reserve network to maximize conservation given a budget constraint. We begin by describing the biological and economic data and then describe the results of the cost-effectiveness analysis.

Data

The study area for this application is roughly the western two-thirds of the State of Oregon. This is the area for which we had both information about land values and biological information about species ranges. The study area was partitioned into 289

potential biological reserve sites by overlaying a hexagonal grid. Each hexagonal grid has an area equal to 635 km^2.

Following Polasky et al. (2001a), the opportunity cost of designating a site as a biological reserve is assumed to be the average per acre land value at the site. In theory, the price of land equals the net present value that accrues from land ownership. In other words, in theory the land value captures the stream of income that the land generates over time, all discounted to the present. For public lands, we estimated the potential net present value of income generated on public land, where income was generated either from timber harvesting or livestock grazing. We used data on forest inventory, forest site productivity data, timber prices and harvest costs to generate present value of timber income. We used data on livestock forage productivity by site as well as livestock prices and costs to generate present value of grazing. Establishing a biological reserve presumes that no economic activity will occur on that land so that land price (or present value of income from economic activity) represents a measure of opportunity cost of selecting the sites as a reserve. Wilderness areas and national parks for which society has decided that conservation is the highest value use were assumed to have no opportunity costs for being set aside as reserves. Of course, there are some values such as recreation or ecosystem service values that may be enhanced by preserving the site in its natural condition. These values are not captured in this study. Details of the assumptions, methods and data sources for the land value figures are described in Garber-Yonts and Polasky (1998) and in Polasky et al. (2001a).

Figure 2 shows average per acre land values for the 289 potential reserve sites. West of the Cascade Range, where forestry and agriculture are productive and most of

the population of Oregon resides, land values tend to be high. Land values are high in the Willamette Valley, particularly on the outskirts of the Portland metropolitan area, in the Rogue River Valley, along the Pacific Coast and near the city of Bend in central Oregon. With the exception of the Bend area, land values are low east of the Cascades.

We record the presence or absence of each of 248 bird species that occur in the study area for each of the 289 potential reserve sites. The data on species presence/absence by site were compiled from records of the Nature Conservancy's Natural Heritage Program, and other sources, for the Biodiversity Research Consortium -- a cooperative agreement among various government agencies for the purposes of collecting and analyzing patterns of biodiversity. A detailed description of this data set is given in Master et al. (1995). In the original data, each species at each site was placed into one of four categories: a) confident -- a verified sighting of the species at the site had occurred in the past two decades; b) probable -- the site contains suitable habitat for the species and there have been verified sightings nearby; c) possible -- no verified sightings have occurred at the site and the site is of questionable suitability for the species; d) not present -- habitat is unsuitable for the species. We assumed that a species was present at a site if and only if it was in the confident or probable categories at the site. In Arthur et al. (forthcoming), Camm et al. (forthcoming) and Polasky et al. (2000), the problem with uncertainties about presence/absence are analyzed. In these papers, probabilities are assigned for the "probable" and "possible" categories and the objective is to maximize expected coverage in a site-constrained problem.

Sibley and Ahlquist (1990) provides phylogenetic distances between numerous bird species of the world based on a measure of DNA-DNA hybridization ($\Delta T_{50} H$

values). This work was most concerned with higher order phylogeny and taxonomy and did not report many of the interspecific distances within a genus. For more complete coverage we use genus rather than species as the unit of analysis. The data for intergeneric distances were taken from branch lengths of UPGMA phylogenetic trees of birds reported in Sibley and Ahlquist (1990:838-870).

Figure 3 shows the number of genera that occur in each potential reserve site. There are a total of 104 genera present in the study area. Genus richness tends to increase in a southerly direction. High pockets of genus richness occur in the Klamath Lake region in southern Oregon (an area noted for its large number of bird species), along the southern central coast, the Steens Mountain area of eastern Oregon and in the Willamette Valley. The high desert areas in the eastern part of the study area contain the fewest genera. Figure 4 shows the phylogenetic diversity across the potential reserve sites. The geographic pattern of phylogenetic diversity is similar to the pattern of genus richness.

Results

To generate results, we applied the greedy algorithm to the reserve site selection problem, where the objective is to maximize either the number of genera represented or phylogenetic diversity of represented genera given a budget constraint. We vary the size of the budget in order to trace out how much coverage can be obtained for varying levels of cost. By doing so we can trace out a cost curve for biodiversity conservation.

Two cost curves– one chosen to maximize richness per dollar spent, the other to maximize diversity per dollar spent – are presented as Figures 5 and 6, respectively. In these figures, costs reported are the sum of the per acre land value for each site chosen as a reserve. Costs reported here should be interpreted in a relative sense only. To accurately calculate total costs of setting up the reserve network, one would have to multiply the cost per acre by the number of acres included in the reserve. For example, if reserves were 10,000 acres each, one would multiply all of the cost number reported here by 10,000 to get total cost. The numbers on the curves, labeled 1 to 16, show how many sites have been included in the reserve network to get to that level of coverage. For example, in figure 5, the cost of covering 70 genera, which can be achieved by selecting 8 sites, is $180.

As illustrated in figure 5, inclusion of the first site, which is quite inexpensive, covers 52 genera. Including sites 2 through 9 is also inexpensive, but only covers an additional 20 genera. All of the first 9 sites chosen are located east crest of the Cascade Mountains where land values are low. At this point there is almost complete coverage of all genera east of the mountains. In order to get more coverage some sites west of the Cascades must be included. The 10th site chosen has much higher land value but adds 14 genera to what had been represented previously. Beyond this point, adding additional reserve sites generally adds one genus at a time from increasingly expensive land. Adding in the 11th to 16th site yields large increases in costs for not much increase in coverage. A similar pattern emerges in figure 6 where the horizontal axis measures phylogenetic diversity rather than genus richness. In both cases, the cost accumulation (total cost) curves for conservation are relatively flat until near complete coverage when

they become quite steep. In other words, it is relatively inexpensive to conserve the majority of representative genera (either in terms of richness or diversity), but the costs of obtaining complete coverage are substantial. For example, when our objective is to maximize richness per dollar spent, conservation costs are $180 for 70 genera ($2.57/genus), $5,235 for 99 genera ($52.88/genus) and $16,061 for all 104 genera ($154.43/genus). In this regard, our results are similar to others reported in the literature (Ando et al., 1998, Montgomery et al. 1994, 1999, Polasky et al. 2001a). For example, Ando et al. (1998) find that conserving 50% of endangered species in the U.S. costs less than 10% of the total cost of covering all endangered species.

Table 2 shows the contribution of sites selected in order of selection when genus richness is the goal. Table 3 gives analogous information about sites when phylogenetic diversity is the goal. The second column shows the number of genera/phylogenetic diversity that occurs at that site. The third column, labeled marginal value of site, shows the number of genera/phylogenetic diversity that inclusion of this site adds that had not been previously conserved at other included sites. The final column shows the total or cumulative genus richness/phylogenetic diversity of including all sites up to that point. Except for the initial site selected, the contribution of the site by itself and the marginal values of each site differ substantially. For example, the 14th site selected when genus richness is the goal has a value of 58 if it was the only existing site, but contributes only genus to the reserve network given that 13 other sites are included in the reserve network. What a particular site contributes to the overall conservation goal is that portion of diversity not covered elsewhere, which is what generates its marginal value. In general,

the marginal value of each site depends heavily on the degree of substitutability or complementarity with other sites.

Conclusions

As discussed in the introduction, conserving biodiversity is an important environmental policy objective. The decline of habitat, which is directly related to land use decisions, is the leading cause of the decline of biodiversity, whether measured at the genetic, species or ecosystem level. Species and habitat conservation considerations already factor into many land use and land management decisions. In the future, attention to conservation considerations in land use and land management is likely to increase in the future as conflicts between human uses and species and habitat conservation increase. Given this, the academic and policy communities should be developing tools that land managers can use to navigate these conflicts as they try to pursue both profitable economic activities and conservation.

In this chapter we have discussed methods for trying to simultaneously pursue both human land use and conservation objectives. The methods we used combine ecological and economic information to maximize biodiversity conservation for a given cost. We illustrated the approach using land value data, taxonomic information, and geographic distribution data of bird species in Oregon. This illustration illuminates several points that we think are relevant for conservation policy generally. First, while some degree of conflict between pursuit of economic activity and conservation may be inevitable, much of biodiversity can be conserved with minimal disruption to the economy. In our results, and those of other studies, a large fraction of biodiversity

conservation can be accomplished at low cost. This result occurs because there are rural areas that contain a large number of species or important habitat that are of marginal value for economic activities. Conserving those places that have high conservation value and low economic value results in protection of a large fraction of biodiversity at very low cost.

Second, complete protection of all biodiversity is likely to be expensive. Some species have limited ranges that occur on land for which high value economic activity could occur. In our study, the protecting the last few bird genera entailed greater expense than protecting the other 90 to 95% of the genera. Cases where conservation entails high cost represent difficult policy choices for society. To date we have not successfully established a policy course for making tradeoffs between conservation and economic activities. In theory, the Endangered Species Act prohibits harm to listed species, which includes adverse habitat modification. The law would seem to imply that conservation should occur regardless of how high the costs might be. In practice, however, political pressures, inadequate funding and lack of knowledge often lead to conservation taking a back seat to economic activity despite what is written in the Endangered Species Act.

Finally, coordinating land use plans that allow pursuit of both economic activity and conservation objectives requires both a broad perspective and attention to local details. Predicting whether a species can survive in a location depends upon detailed knowledge of local conditions. How important it is that a species survives in that locale depends in large part on whether it is one of many populations or the last remaining population of the species. If there are large relatively safe populations of the species that exist in other locations, then it is less important to safeguard the species in this particular

locale. However, it would be of great importance to conserve a species if by losing this population causes the overall extinction of the species. Similarly, a case can be made that species with no close genetic relatives may be of greater conservation importance than species with close genetic relatives as losing the former will result in greater loss of unique genetic material. Understanding the marginal contribution of particular species or particular habitats can only be done with knowledge of the bigger picture: what other habitats and species are likely to be conserved. One challenge to conservation planning is to successfully coordinate the big picture with local detailed information and local land managers responsible for land use and land management decisions on their land.

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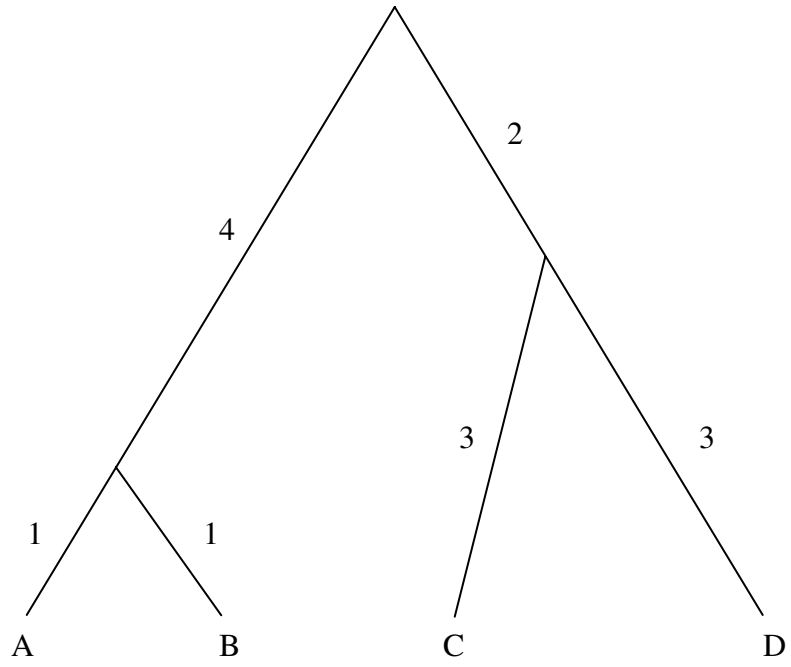**Figure 1. Example phylogenetic tree for a set of four genera**
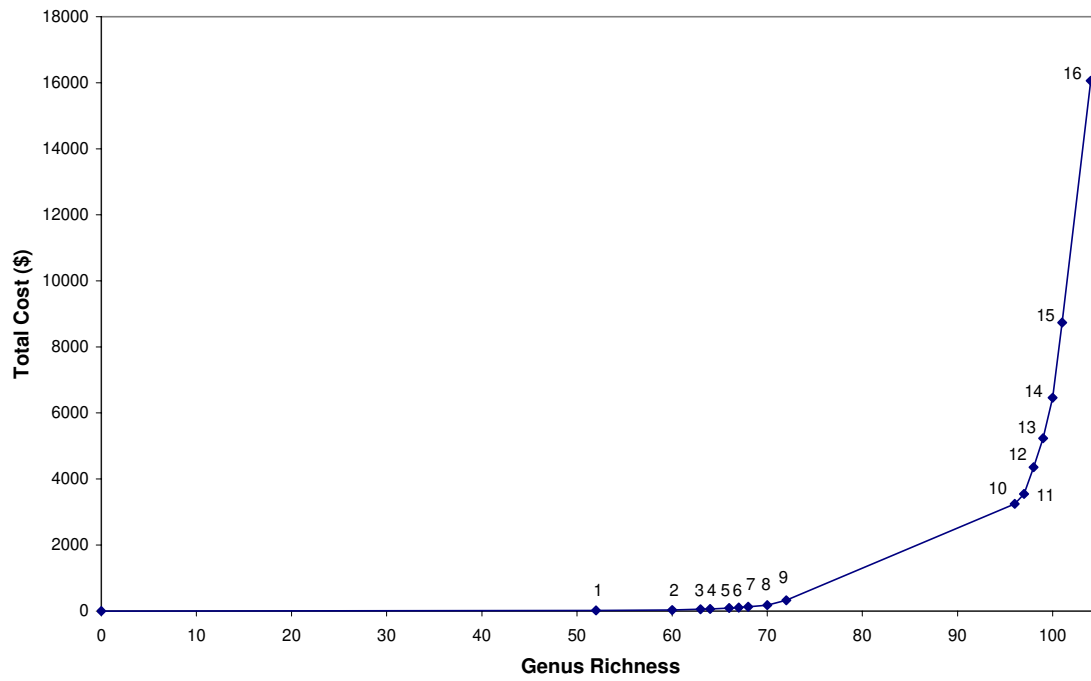
Figure 5. Richness Cost Accumulation Curve
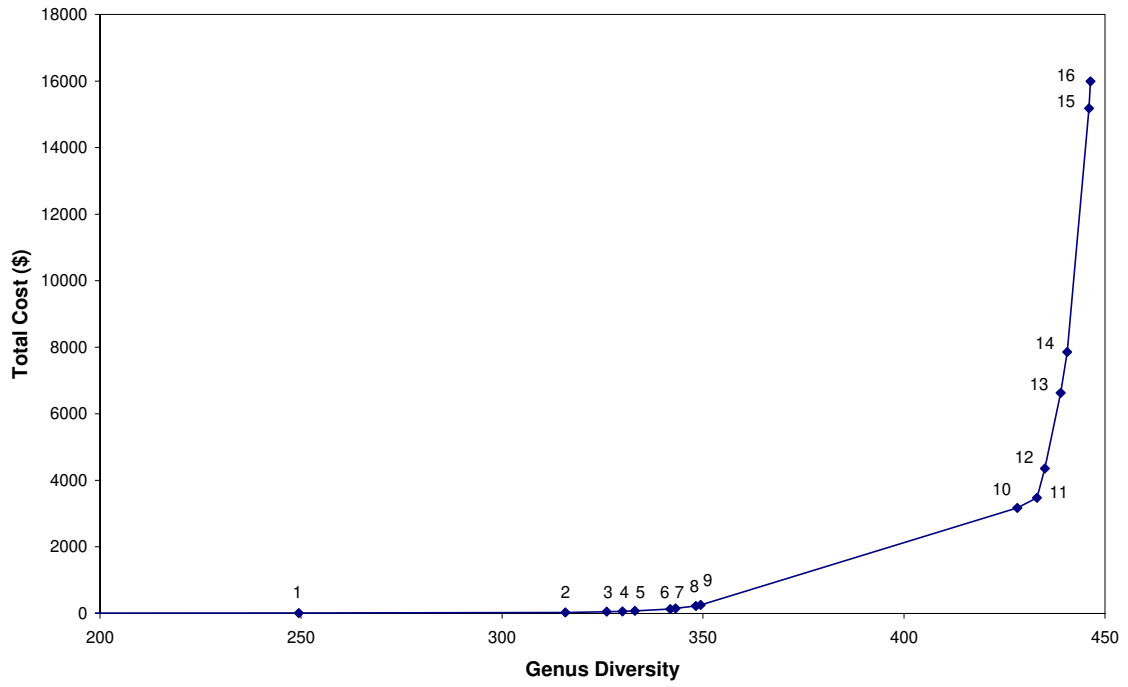
Figure 6. Diversity Cost Accumulation Curve

Table 1. Example Where The Greedy Algorithm Fails to Pick Optimally		
A	B	C
1	1	3
2	2	4
3	5	6
4		

Order Selected	Value if it were the only site selected[*]	Marginal Value of site	Total Value of sites
	Table 2. Marginal Value of Sites Selected according to the		
	Genus Richness - Greedy Algorithm		
1	52	52	52
2	42	8	60
3	19	3	63
4	12	1	64
5	54	2	66
6	12	1	67
7	12	1	68
8	53	2	70
9	21	2	72
10	60	14	96
11	26	1	97
12	54	1	98
13	24	1	99
14	58	1	100
15	21	1	101
16	63	3	104
*In this context, value only refers to the number of genera represented by a given site			

Table 3. Marginal Value of Sites Selected according to the Genus Diversity - Greedy Algorithm

Order Selected	Value if it were the only site selected[*]	Marginal Value of site	Total Value of sites
1	249.45	249.45	249.45
2	286.95	66.3	315.75
3	246.95	10.3	326.05
4	81.15	3.9	329.95
5	83.65	3.1	333.05
6	284.65	8.8	341.85
7	78.55	1.3	343.15
8	243.75	5.05	348.20
9	289.4	1.25	349.45
10	307.45	78.7	428.15
11	167.95	4.9	433.05
12	154.35	2.0	435.05
13	134.5	3.9	438.95
14	305.9	1.6	440.55
15	306.95	5.45	446.00
16	293	0.35	446.35

*In this context, value only refers to the diversity measures as calculated by Sibley and Ahlquist (1990)