AN ABSTRACT OF THE THESIS OF

Neal J. Shunk for the degree of Master of Science in Forest Resources presented on October 5, 2000. Title: Choosing Efficient Land Allocations and Forest Management Regimes for Biodiversity.

Abstract approved: Signature redacted for privacy.

Claire A. Montgomery

Increasing rates of species imperilment and the loss of biological diversity in naturally functioning ecosystems can be directly linked to accelerated urban development and the conversion of natural habitats to satisfy the needs of man. In combating this loss of biodiversity, scientists and policy makers alike recognize the relevance of habitat conservation. This research, funded by a cooperative grant with USDA Forest Service, relies on a framework for modeling wildlife diversity presented by Montgomery et al (1999), to reveal cost effective habitat conservation strategies. Building on this earlier model, alternative forest management strategies are introduced: information that is vital to timber-based economies.

196 mammalian, reptilian, amphibian, and avian species were used to construct a biodiversity index relevant to the Muddy Creek Watershed, Benton County, Oregon. This index, comprised of a taxonomic diversity measure (May 1990) and a classic logistic viability function, measured gains in biodiversity scaled against the opportunity costs of reallocating lands to meet conservation goals. These

index values and associated opportunity costs were calculated and reserved across the full range of land allocation possibilities for the watershed, and formed a marginal cost curve for biodiversity.

The wildlife diversity index ranges in value from 296.19, corresponding to a high development market value maximizing solution, to 310.18 at a cost of nearly 460 million dollars, the highest attainable biodiversity index for this watershed. Forest management played an integral role in the conservation of biodiversity, whereby biodiversity maximizing solutions allocated an overwhelming percentage of forested lands to non-harvested forested reserves.

Two supplementary analyses were undertaken. The first tracked changes in the biodiversity index when management strategies targeting imperiled species were specifically optimized. Land allocations favoring these species had drastic implications on the predicted populations of the remaining non-imperiled species, indicative of the need to consider a broader set of species and their related needs in future land management planning efforts. The second, examined the efficiency of the Institute for a Sustainable Environment's (ISE) high conservation land allocation projections for the year 2025, and verified the necessity of biological indicators in land planning.

Choosing Efficient Land Allocations and Forest Management Regimes for Biodiversity

by

Neal J. Shunk

A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented October 5, 2000
Commencement June 2001

Master of Science thesis of Neal J. Shunk presented on October 5, 2000

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Acknowledgements

In avoiding an Emmy-like acceptance, I will attempt to be brief.

I would like to first thank Claire Montgomery for her persistent direction, encouragement, and genuine interest in my academic achievements. I would also like to thank the USDA Forest Service and the Oregon State University Department of Forest Resources, whose cooperative agreement financed this research.

On a personal note, I thank Darius Adams and John Sessions for the knowledge they have shared with me over the last two years. In addition, a special thanks to those who have contributed their time and expertise to this project, including my graduate committee representatives; Douglas Brodie, Denis White, Junjie Wu, and Thomas McLain.

Finally, I must thank my wife, Kylie, for her patience, love, and support; and our families and friends who encouraged our Pacific northwest adventures.

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CHOOSING EFFICIENT LAND ALLOCATIONS AND FOREST MANAGEMENT REGIMES FOR BIODIVERSITY

1.0 INTRODUCTION

Declining levels of biodiversity is of growing concern. With urbanization rates steadily climbing, the need for understanding how current land allocations and land use decisions impact our ecological diversity is apparent. In October of 1997 more than six hundred world-renowned scientists met in Washington, D.C. to review the current state of biodiversity worldwide. This group estimated that "species are disappearing at more than 1,000 times the normal rate," and that "seventy five percent of the world's species will be extinct by the end of the next century" (Jewett 1997).

These alarming extinction rates have been the focus of debate for decades, and have ultimately led to a stronger emphasis on wildlife conservation in land use and forest planning. Consider for instance the USDA Forest Service policy initiatives spawned from declining populations of the Northern Spotted Owl, and more recent concerns and activities relating to the preservation of wild salmonid species throughout the Pacific Northwest (Independent Multidisciplinary Science Team 1999).

These programs, aimed at restoring viable breeding populations to endangered species, have proven costly over recent decades. Scientists and policy makers alike now recognize the importance of identifying critical habitats for all species before current populations decline to levels associated with endangerment. This broader concern for ecological diversity has both heightened awareness of the surrounding issues, and generated millions of research dollars applicable to biodiversity studies. The Oregon Biodiversity Project for example, begun in 1994, has spent four years and over a million dollars mapping Oregon's wildlife habitats (Denson 1999).

Projects like these play an integral role in defining future alternatives for the management of biodiversity. Describing current conditions of ecosystems, and biological relationships that exist between species and their habitats is a necessary first step towards defining an efficient framework for managing for biodiversity. Economists have used such information to examine a variety of related questions regarding future land management and associated gains in wildlife diversity, termed recently as 'the calculus of biodiversity' (May 1990).

These economic studies have added to a growing base of literature addressing the tradeoffs associated with societal demands for natural resources and wildlife biodiversity. Authors have examined a range of associated topics from a cost effective reserve site selection that is both spatial (Csuti et al. 1997a) and non-spatial (Faith et al. 1996), to research aimed at identifying the marginal cost of single species viability (Montgomery et al. 1994, Hyde 1989, Haight et al. 2000). "Pricing Biodiversity" (Montgomery et al.1999) addressed efficient land allocation decisions for varying target levels of biodiversity That study laid the foundation upon which I have constructed my own assessment of biodiversity in the Muddy Creek Watershed, Benton County, Oregon. The Muddy Creek Project utilizes Montgomery's framework for modeling the expected diversity of a given area as a function of species viability and uniqueness. Revealing cost effective tradeoffs between market valued uses and the conservation of biodiversity, the study introduces methodologies that capture the idea of managing forests for both timber production and wildlife habitat.

The project is aimed at defining efficient land use allocations when biodiversity is of concern. As such, the research finds optimal arrangements of favored habitat at the minimal cost. One hundred ninety six wildlife species are evaluated for their contribution to expected biodiversity, and marginal cost curves are presented for a range of associated habitat allocations. In addition, the study contrasts a diversity index dependent on the wildlife diversity depicted by the full range of species examined, and a second representative of management strategies targeting imperiled and critically imperiled species alone. Current forest management regimes, and the impact that changes in these regimes will bring to the expected biodiversity measure, are examined for both indices.

1.1 Objectives

The overall objective of this research is the continued development and analysis of tradeoffs associated with land allocation and the conservation of wildlife biodiversity. The study will focus upon the application and further development of earlier models to evaluate the current state and possible futures of biodiversity in the Muddy Creek Watershed.

In defining efficient land allocations and the tradeoffs between market valued and conservation favoring land uses, a marginal cost curve for biodiversity represents the optimal arrangement of habitats for a range of relative values for wildlife diversity. Points along this marginal cost curve represent optimal choices for local land managers, and represent the full range of efficient choices for the protection of biodiversity in the watershed. Such information is the fundamental objective of this research and corresponds to the following project objectives:

1. Construct a marginal cost curve for biodiversity relative to the Muddy Creek Watershed.
2. Examine shifts in current forest management regimes resulting from an increased willingness to pay for biodiversity.
3. Develop and contrast a diversity index representative of management strategies targeting imperiled species.
4. Examine the "Possible Futures for the Muddy Creek Watershed, Benton County, Oregon" (Hulse et al. 1997) high conservation landscape's contribution to species population indices, and the resulting efficiency of such solutions.

1.2 Literature Review

Human encroachment into previously undisturbed or natural areas has had a direct influence on declining levels of biodiversity. Examining the degree man has influenced shrinking native wildlife populations, as well as defining land management alternatives that most efficiently slow these declines, has led to the amalgamation of biological and economic principles.

In analyzing the tradeoffs that exist between the conservation of wildlife diversity and market valued uses, authors have drawn on a variety of disciplines and examined a range of related topics. These studies have yielded information relating to population viability, diversity measures, efficient multiple use forest management, reserve site selection, and multiple species biodiversity models. Each will be reviewed in turn.

1.2.1 Viability Functions

Economic principles applied to the biodiversity dilemma have been fruitful. Stated simply, "Economics matters because human behavior generally, and economic parameters in particular, help to determine the degree of risk to a species" (Shogren et al. 1999). Defining this degree of risk to a species is often viewed conversely as the probability of species survival, with survival rates typically demonstrated as viability functions.

Viability functions approximate the relationship that exists between population size, given as a function of habitat availability and/or species-specific traits, and the probability of species survival. These curves are often specified as logarithmic, capturing the population dynamics and critical densities associated with a species. This represents larger, marginal viability gains for populations of modest but not yet critical size, whereas lesser marginal gains are associated with the contribution of an additional member to an already thriving population. The Allee effect, depicted by the left tail of the viability function, reflects the imperilment of endangered species. Thus, the probability that an offspring successfully reproduces approaches zero as population size diminishes past a critical threshold due to both the lack of available breeding partners and the distance that species may have to travel to find such a mate.

Early viability modeling efforts were typically focused on depicting the ecological and biological characteristics inherent to the survival of a particular species. Armbruster and Lande (1993), for example, examined the population dynamics of African Elephants in the Tsavo National Park, Kenya. Based upon species fecundity, survivorship, and landscape dynamics, elephant viability was forecasted based upon reserve size. Ruggiero et al.(1994), suggested that viability may best be described by evaluating the following six indicators: disjoint or connection of habitat, habitat separation, age class of forested habitats, habitat size, reproduction rates, and environmental conditions affecting carrying capacities.

In evaluating viabilities for multi-species modeling, data relating to habitat structure and individual specific indicators are difficult to obtain. The International Union for Conservation of Nature and Natural Resources (IUCN) is one of many conservation groups globally that assess species imperilment, where species are assigned an imperilment ranking based upon extent of occurrences, area of occupancy, area and quality of habitat, frequency and locations of sub-populations, and number of mature individuals (IUCN 1994). Mace and Lande (1991), and Mace and Stuart (1994), in association with the IUCN, defined the probability of survival over a specified time horizon given a species' IUCN imperilment ranking. Utilizing these probabilities of survival and the estimated population size intrinsic to the ranking system, Montgomery et al. (1999) constructed a viability curve for use in depicting population dynamics for all species that have been classified according to IUCN ranking standards.

1.2.2 Diversity Measures

Diversity measures aid in distinguishing priorities for conservation, a goal inherent to modeling biological diversity. Priorities are often influenced by a species' relative uniqueness, but preference could also be influenced by aesthetic uniqueness, contribution to ecosystem function, species interdependence, or humanistic features such as future medicinal importance, intrinsic value as watchable wildlife, or potential sociological symbolism.

Taxonomic distinctiveness, sometimes used to summarize the contribution of species uniqueness to a biodiversity index, is typically represented by cladistic-based measurements. Although favorable in some circumstances genetic-based distance measures (Krajewski 1994, Faith 1994, Farris 1979) are rare for most species, and thus their practical application in most studies is not feasible. One such example, Solow et al. (1993) utilized a set of pair-wise genetic distances to differentiate diversity in fourteen crane species.

Cladistic-based diversity measures, attributable to May (1990) and Vane–Wright et al. (1991), define uniqueness based upon weighted (Cousins 1991) or unweighted taxonomic trees. This approach requires less data, a location specific cladogram, and is a system by which species are ranked relative to one another. The methodology develops diversity rankings based on the number of taxonomically related species sharing the same family, order, or genus, and is a common approach to account for species uniqueness in current biodiversity studies.

1.2.3 Efficient Multiple Use Forest Management

Research aimed at identifying efficient forest management regimes, and the tradeoffs that exist between timber production and habitat protection, has been ongoing for several years. Such information is crucial to forest planners, who often work under state-level and congressional directives aimed at reducing biological risk stemming from management.

Initially, such research was aimed at identifying cost effective alternative management actions and the implications these actions had on single species viability. Biologists would often act as the catalyst for management, indicating appropriate keystone or indicator species, whereas threatened or endangered species were the general focus of most early modeling efforts. Biodiversity in these frameworks was negatively impacted by declines in an already endangered species' population.

These single species models ordinarily defined efficient landscape allocations in the face of species' endangerment or extinction. Hyde (1989), established one of the first of these single species models, associating the marginal cost of red-cockaded woodpecker habitat preservation with increased viability for the species. In a similar study, Montgomery et al. (1994) defined the marginal cost of northern spotted owl critical habitat relying on population dynamic models (Lamberson et al. 1992). This model linked the probability of owl survival to reductions in annual timber supply from federal forests in the Pacific northwest.

Haight (1995), presented a generalized model for extinction risk and economic costs in forest planning. This stochastic simulation model suggested methodologies relying on common economic maximization techniques and constrained by minimum allowable population risk, to determine cost effective conservation plans. The model, repeatedly solved for varying levels of risk, is notable in that it attempts to provide a framework by which USDA Forest Service regulations for sensitive species can actually be accounted for in long-term management planning.

As an application of this framework, Haight, (1999) suggested efficient land management solutions for habitat availability for the San Joaquin kit fox. Re-solving this model with incrementally higher upper bounds on funding, the authors suggested optimal habitat protection areas based on the probability of population extinction, size of protection area, and total amount of funding, subject to a budget constraint.

1.2.4 Reserve Site Selection

A broader class of algorithms, reserve site selection optimizers, define efficient biological reserve areas given current habitat configurations, costs for acquisition, and species habitat requirements. One such example (Ando et al. 1998), utilized integer-programming techniques to select reserve areas based upon county level data on land prices and the distribution of endangered species within the United States. A similar approach, Csuti et al. (1997a), compared the efficiency of four reserve site selection algorithms for an Oregon specific terrestrial vertebrate data set. The study contrasted the effects of selecting reserves based on species rarity or endangerment, maximizing species uniqueness indicators. This study did not, however, incorporate land value constraints in the optimization process.

An alternative approach (Haight et al. 2000), introduced reserve selection methodologies that maximized the occurrence of vegetative communities subject to a budget constraint. Based upon the uncertainty of species presence or absence data the authors relied on probabilistic integer optimization techniques to forecast efficient site reserves. In this framework, a vegetative community contributed to the reserve site's production potential when its probability of occurrence exceeded minimum reliability thresholds.

1.2.5 Multiple Species Biodiversity Models

Multi-species land allocation or management problems, incorporate many of the ideas already discussed relating to population viability analysis, species uniqueness indicators, single-species biodiversity models, and reserve site selection algorithms. They are unique, however, in that they typically indicate the expected gains in multi-species biodiversity based on future land management policy scenarios. This information is key to the ongoing debate defining what biodiversity is, and how our land management decisions today can be reflected in future healthy populations of wildlife species.

White et al. (1997), for example, assessed multiple species risk by devising species abundance measures predicted by species area requirements, frequency of habitat, and patch size. Implications of future biodiversity changes were tracked across predicted future landscapes, defining a ratio of present to future species abundance.

Rather than defining the change in biodiversity for predicted future landscapes, other authors have chosen to take an economic approach to modeling species-habitat relationships, where efficient or optimal landscape patterns that either meet biodiversity objectives at the minimal cost, or track changes in biodiversity for an increased willingness to pay for the commodity. Hof and Raphael (1992) and Bevers et al. (1995) for instance, defined optimal timber age–class distributions and forest cover types respectively, when constrained by population viability requirements for biodiversity.

Montgomery et al. (1999), developed a marginal cost curve for 147 native bird species in the Poconos region of Monroe County, Pennsylvania. This study traced the supply of expected diversity for incremental changes in the willingness to pay for biodiversity, expressed as foregone land value as land uses changed to accommodate biodiversity. The study incorporated measures of species viability and uniqueness (cladistic-based) that uniquely distinguished it from earlier models relying on population maximizing algorithms.

1.2.6 Literature Review Conclusion

Currently, modeling efforts are constrained by the type and validity of biological data available. With advancements in technology and computing capabilities, spatial heuristic solutions to landscape problems could present new opportunities to further our understanding of biodiversity management. Current efforts typically optimize spatial habitat configurations, edge, and/or fragmentation, like Shannon's index (Holland 1994).

Scientific data relating species preference and interaction with specific habitat characteristics, however, is lacking for most species. With the further development of such measures for all species, future land allocation solutions for biodiversity, and the information contained therein, will surely add to our further understanding of the preservation of wild populations.

Given the information currently available, however, this project revealed efficient land allocation alternatives, relying on a biodiversity index similar to Montgomery et al. (1999). Based on the watershed's timber reliant economy a number of forest management alternatives were presented, and gains in biodiversity brought about by changes in current management regimes were forecasted. In addition, the implications of land management strategies targeting imperiled species, as well as community group landscape planning efforts were analyzed. The project united earlier biological diversity models and defined efficient habitat protection strategies for multi-species biodiversity.

2.0 METHODS

2.1 Study Site Description

The Muddy Creek Watershed, Benton County, Oregon, encompasses some 125 square miles (32,000 hectares) in the Willamette River Basin of Western Oregon. The watershed is situated on the east side of the Oregon Coast Range, southwest of Corvallis, Oregon (Figure 1).

Figure 1. Location Map (Hulse et al. 1997).

Elevation ranges from approximately 200 feet above sea level to nearly 2,000 feet on the western most edge of the unit. Of the 79,000 acres, eighty percent is privately owned, some seven percent is contained in the Finley National Wildlife refuge, and the remaining thirteen percent's ownership is attributable to the State of Oregon, U.S.D.A. Forest Service, and the Bureau of Land Management. Approximately three percent of the privately owned acreage is zoned rural-residential, housing some 3,000 residents with typical lot sizes ranging from two to five acres.

There are an estimated 196 mammalian, amphibian, reptilian, and avian species that are thought to currently exist in the watershed. The 196 species modeled represent species that were not locally extirpated or introduced, and preferred at least one of the land-use habitats represented by this study (see Appendix 1 for a complete list of species, diversity weights, and IUCN imperilment ranks). Based on Oregon Natural Heritage (1999) IUCN imperilment rankings, seven of these species are considered imperiled, thirteen are listed as vulnerable, seventy-eight of the species are currently classified as apparently secure, and the remaining ninety-eight species are listed as secure under present conditions. Habitat preferences are variable and range from species that rely on forested and open habitats for nesting and home ranges, to species like the cliff swallow (*Hirundo pyrrhonota*) that thrive in the commercial/residential communities of the watershed.

Accommodating these wildlife species, the Muddy Creek Watershed encompasses a diverse mix of agriculturally productive, natural-open, residential, and forestry related lands. Elevation, soil type, and slope generally characterize where we would expect to find such uses, with residential lands scattered amongst the agricultural (higher quality soils) and open (poorer soils) land uses typically observed at lower elevations, and forested lands being observed at higher elevations.

The watershed's northeastern most edge abuts against the Corvallis urban growth boundary, a zone where there has been residential expansion in recent years to accommodate the growing population in the surrounding areas. Transportation routes through the drainage range from a secondary highway, 99E, to maintained logging roads covering the upland hillsides. Much of the area is zoned for agriculture and forestry related uses, and as can be noted by driving through the area, recent clear-cuts and a centrally located mill indicate the community's continued reliance on its timber base as a major source of income.

1990 land-use in the Muddy Creek Watershed is depicted by Figure 2. This illustration comes from the Institute for a Sustainable Environment (ISE), who developed a set of geographic information system (GIS) coverages related to the watershed. These 30 meter grids depict 1990 land-use, 2025 projections of land-use based on trends in use and assumptions regarding future management emphasis, elevation, slope, and soil type.

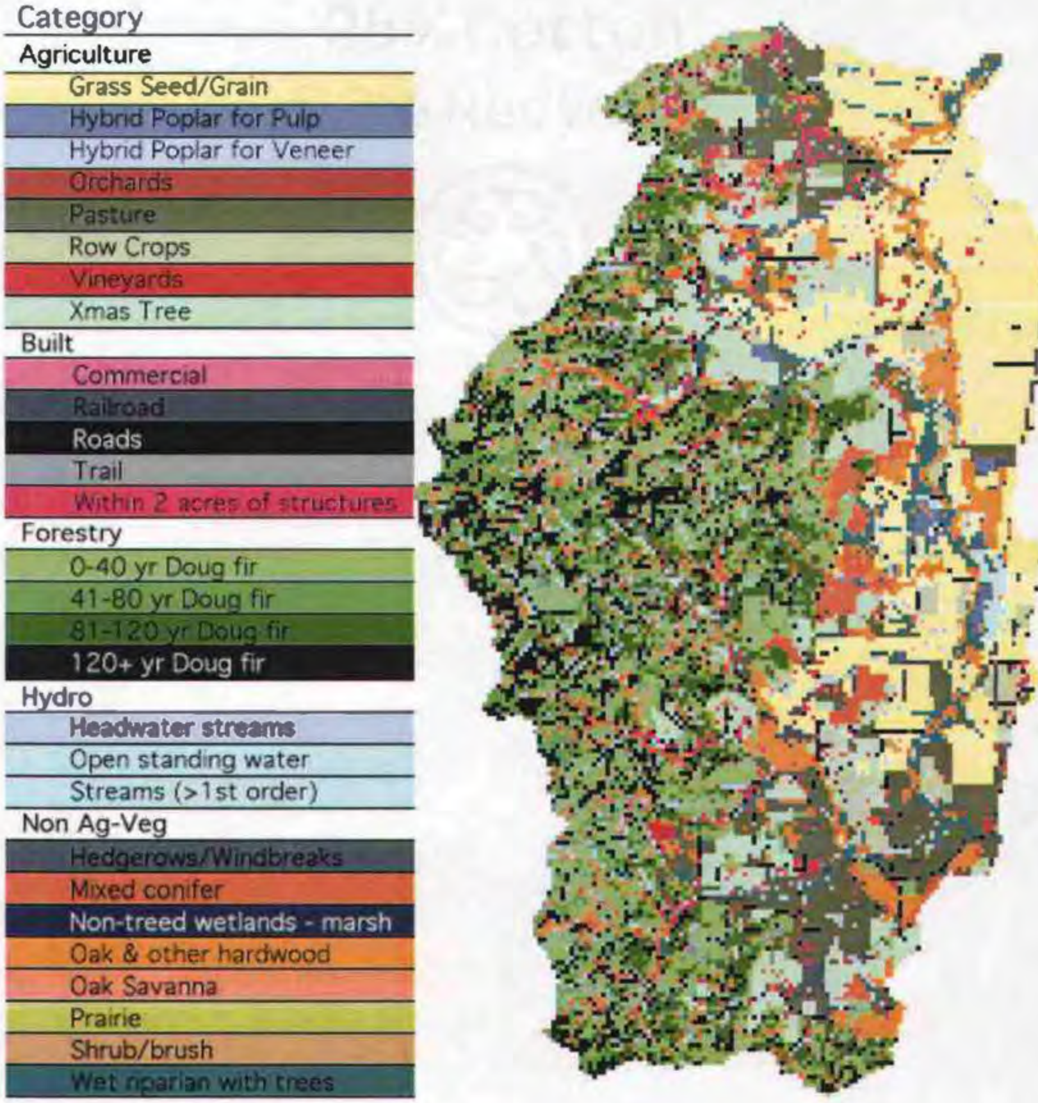


Figure 2. 1990 Land Use (Hulse et al. 1997).

The ISE's GIS representations of the watershed were further aggregated for modeling purposes. The ISE's classes were further aggregated by the Muddy project habitat team into 26 wildlife habitat classes. Utilizing ArcInfo and ARCView spatial analysis software, six slope-soil based site classes, and four land-use classes; commercial/residential, agriculturally based, open, and forested use were defined. These site types, and land uses were an aggregate representation of the wildlife habitat classes. The land use aggregations were the same "use" classes that the Muddy project habitat team adopted to characterize the landscape (see Table 1), and were coincidentally highly correlated with species habitat preferences.

Wildlife Habitat Classes	**Habitat Aggregations**
0-40 Douglas-fir	0-40 Douglas-fir
40-80 Douglas-fir	40-80 Douglas-fir
80-120+ Douglas-fir	80-120+ Douglas-fir
Mixed species forest	Open
Deciduous forest	Open
Low riparian	N/A
Low Marsh	N/A
Low stream 1st order	N/A
Up stream 1st order	N/A
Low stream 2nd order	N/A
Up stream 2nd order	N/A
Low water	N/A
Up water	N/A
Shrub	Open
Hedge	Open
Oak	Open
Prairie	Agriculture
Row crops	Agriculture
Grass seed production	Agriculture
Pasture	Agriculture
Christmas tree plantations	Agriculture
Hybrid Poplar plantations	Agriculture
Orchards	Agriculture
Commercial/Residential	Residential
Roadside	N/A
Site Characteristics	**Soil-Slope Site Class**
Good soils, slope < 10% slope	1
Good Soils, slope > 10% slope	2
Moderate soils < 10% slope	3
Moderate soils > 10% slope	4
Poor soils < 10% slope	5
Poor soils > 10% slope	6

Table 1: Habitat and Soil – Slope Aggregations.

Given these land-use classes, as well as species' preferences for such habitats, the construction of a wildlife diversity index and a supply curve for biodiversity was possible. The methods for achieving this objective follow.

2.2 A Marginal Cost Curve for Biodiversity

A marginal cost curve for biodiversity represents a continuum of efficient land allocation opportunities that exist for the Muddy Creek Watershed. This supply curve measures gains in biodiversity against the opportunity cost of foregone land value as lands are reallocated to favor wildlife conservation over other market valued uses. As such, it is representative of meeting a desired level of biological protection at the minimum cost. Utilizing this information a hypothetical land manager would have the ability to make informed, efficient decisions with regards to biodiversity and land allocations. Moreover, this manager would have the ability to choose optimal land allocations for biodiversity given a budget constraint.

This marginal cost curve was revealed by evaluating future land-use allocations and the tradeoffs that existed between biological conservation and commodity production. Biodiversity and market value maximizing solutions were jointly solved by maximizing an additive objective function for total watershed value (see Equation 1). This was accomplished by the development of an objective function capturing both the dynamics of wildlife biodiversity, and market valued uses. Each will be reviewed in turn.

$$\text{Total Watershed Value} = \text{Market Value} + \text{Biodiversity Value} \qquad (1)$$

2.2.1 Evaluating Biodiversity

Biodiversity by definition reflects a diverse and abundant population of all native species. In modeling multi-species biodiversity it makes intuitive sense to formulate an index that captures both the diversity that an individual species contributes to the overall ecological system, and the probability that the species will actually contribute this diversity to future generations based on current population size and extinction rates.

Montgomery et al. (1999), was able to describe these effects simultaneously: a framework utilized throughout this project to characterize expected wildlife biodiversity. This framework relied on the use of an International Union for Conservation of Nature and Natural Resources (IUCN) Red List Category-based viability function, and the construction of taxonomically based uniqueness rankings.

The viability curve and species uniqueness weights were constructed for 196 of the 234 mammalian, reptilian, avian, and amphibian species, (S), that exist in the Muddy Creek Watershed (Hulse 1997). A general species viability relationship (Vs) was constructed based upon IUCN Red List Category D classes. (These red list categories define degree of imperilment in terms of the expected population size (Ps) of a species and an implied probability of extinction over a defined time horizon (Mace and Lande 1991, Mace and Stuart 1994)). By normalizing these rates of extinction over a single time period, a relationship between population size and probability of survival was determined. A logistic curve was then fitted through the mean population size and the corresponding probability of survival for each of the red list categories, represented by Equation 2. Given the universal nature of this function, this relationship was used to estimate the viability for each of the species in this study.

$$V_s = (1 + \exp(-3.2 - 1.9 * \ln((Ps)/1000)))^{-1} \quad (2)$$

Viability, V_s, within this framework, relies on an implied population size given a certain configuration of habitats or land uses. For example, as more acres of old growth forest are preserved, one might expect the viability of species that prefer such habitat to increase.

To capture such an effect, expected population size, P_s, for each species, s, is dependent on species-specific habitat preferences relative to the Muddy Creek Watershed (White et al. 1997) (see Equation 3). These preferences, determined by a team of biologists familiar with the species of the site, are an integer suitability score of species habitat preference from zero to ten for twenty-six of the land-use categories modeled by the ISE (see Appendix 2 for a complete list habitat preference rankings). Given these habitat preference rankings and implied populations based on the Oregon Nature Conservancy's species specific IUCN endangerment ratings, an average individual per acre measurement, X_{sk}, was constructed for all species, s, and land-uses, k, relative to the study based on current habitat allocations (see Appendix 3). This density index, X_{sk}, was a fixed measure in the optimization process that required two assumptions for estimation: 1) the proportion of habitat types within each land-use class were fixed, 2) IUCN imperilement rankings were representative of current land allocations in the watershed.

X_{sk} = Individual per acre indices for each species in each land-use class.

Where:

P_{IUCN} = Original IUCN population estimate

HP_{sk} = Habitat Preference Rank

$$X_{sk} = [\, P_{IUCN} * [\, (HP_{sk} * Q_k) \;/\; (\sum_{k=1}^{10} HP_{sk} * Q_k) \,]^{-1} \,] * Q_k^{-1}$$

Population density indices, P_s, were then calculated based on the measure, X_{sk}, and land-use allotments, Q_{jk} (Equation 3).

$$P_s = \sum_{k=1}^{10} (X_{sk} * \sum_{j=1}^{6} Q_{jk}) \qquad (3)$$

Where:

P_s = Species population index

k = Land-use: residential, agricultural, open, forest

Where: Forest use alternatives include

40 year fully regulated forest
45 year fully regulated forest
50 year fully regulated forest
60 year fully regulated forest
80 year fully regulated forest
120 year fully regulated forest
Park, non-harvested forest

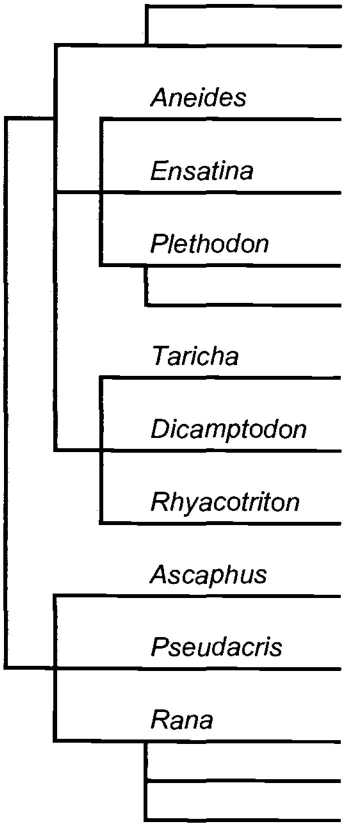
j = Slope and soil based site class

Q_{jk} = Acres of land allocated to each site class and land-use class.

Individual diversity weights, W_s, were constructed for each species, s, based on a hybrid of the taxonomic diversity index proposed by Vane-Wright et al. (1991). A cladogram specific to the Muddy Creek Watershed was first constructed by eliminating all extirpated, and non-watershed related species from an Oregon specific cladogram (Huso 1999).

Initially, the number of species joined at each of the taxonomic tree's nodes were summed. The node counts were then utilized to develop diversity weights (Ws) by taking the inverse of the node count and normalizing to one for the least unique species in each of the four taxonomic divisions of the study: mammalian, reptilian, avian, and amphibian. An example of a cladogram, node counts, and diversity weights for amphibian species present in the Muddy Creek Watershed follows in Figure 3.

For this representation of diversity, species with more close taxonomic relatives have higher node counts, and in turn lower diversity weights. The species with the highest node counts received diversity weights of 1, the lowest possible rank. In contrast, a unique species like the tailed frog, *Ascaphus truei* (depicted in Figure 3), received a higher diversity weight because of their low relative node count. (The tailed frog's node count of five corresponds to the two branches at the class level, and three divisions at the order level, of this species' taxonomic tree).



C	O	F	Genus	Species	Node Count	Diversity Weight
			Ambystoma	*Gracile*	7	1.4285714
				Macrodactylum	7	1.4285714
			Aneides	*Terreus*	8	1.25
			Ensatina	*Eschscholtzii*	8	1.25
			Plethodon	*Dunni*	10	1
				Vehiculum	10	1
			Taricha	*Granulosa*	8	1.25
			Dicamptodon	*Tenebrosus*	8	1.25
			Rhyacotriton	*Variegatus*	8	1.25
			Ascaphus	*Truei*	5	2
			Pseudacris	*Regilla*	5	2
			Rana	*Aurora*	8	1.25
				Catesbeiana	8	1.25
				Pretiosa	8	1.25

Figure 3. Cladogram and Diversity Weights

Expected wildlife biodiversity , E(D), was then given by the product of individual viability functions, $V_s(P_s)$, and diversity weights, W_s, summed across all species, illustrated by Equation 4.

$$E(D) = \sum_{s=1}^{196} V_s(P_s) * W_s \qquad (4)$$

2.2.2 Market Values

Market values play an integral role in the development of a marginal cost curve for biodiversity, as these values are used to gauge the opportunity cost of reallocating lands to increase biodiversity protection. But designing a mechanism to accurately reflect the marginal change in watershed land value as an acre(s) of land is converted from one use to another is a difficult exercise.

As a starting point, weighted average land values were determined for the four land-use classes and six soil/slope types. These values were derived by reclassifying and overlaying the ISE's 30 meter grids for 1990 land use, soil type, and slope, with a coverage of tax assessed land values provided to the project by the Benton County Tax Assessors office.

Given these weighted average land values, the opportunity cost of reallocating lands could be directly assigned as the difference in land value between the two uses for which a conversion is made. Several authors have taken this approach including Ando et al. (1998). Relying on average values alone, however, one must assume that marginal land prices are fixed. In other words, even if the entire watershed's land-use was converted to a single use, the marginal value of that land, as well as that of other uses would remain constant and equal to the average value. This assumption is quite limiting, and the only reasonable application would be for situations where management areas are quite small. Thus, converting the entire parcel to a new use would have no impact on how neighboring economies value their land. Presuming that free market forces work, and that a land's currently observed use is its most valued use, this does not seem like a logical assumption to make for this case study.

Instead, a representation of land value that was sensitive to changes in land allocations was needed. The ideal model would accurately reflect changes in the marginal value of land as lands are reallocated, consistent with a classically shaped downward sloping market demand curve for land. O'Sullivan (1993), discusses a useful construct for such an approach, whereby land value functions for each land-use follow a gradient with respect to some variable. O'Sullivan demonstrates this idea utilizing distance from urban center.

For this study, attempts were made to develop these land value functions utilizing elevation as the gradient variable. With the development of such functions, the unobserved portions of the land value curves could be utilized to predict the opportunity cost of reallocating lands. Consider residential lands for example. This land-use is typically observed at lower elevations than forested uses for this watershed. Thus, the marginal value of an additional acre of residential land, is likely going to be much higher at lower elevations where road systems and residential infrastructures are already in place to deal with the needs of such uses. And, an acre of land at the top of a roadless mountain is valued less for residential use, which is unobserved and unknown without estimation, than for its production potential in forestry. Both of these ideas are captured through the development of land value functions.

Hedonic pricing was used to empirically estimate these land value functions. This methodology utilized plot level data on site characteristics and value to estimate land attribute prices (Lopez et al. 1994,Turner et al.1991). For this study, econometric estimation yielded poor results (R-squared(s) of less than .1, and over-valued residential land-use coefficients). Presuming that we observe an acre's highest valued use, the margins of land area attributable to each land-use did not correspond to this empirical estimation. Ordinary least squares and ordinary least squares corrected for selectivity bias, following the Heckman two-step method, were used to determine land attribute prices. Value was regressed on several combinations of data relating to slope, ownership, zoning, soils, land-use, elevation, and proximity to roads and city centers. Though still an area of continued research, these efforts were ultimately abandoned for this project based on the feasibility of the estimates.

Instead, demand curves were constructed for six slope-soil based site classes and four land-use classes; commercial/residential, agriculturally based, open, and forested use. These linear demand curves, ordered from the highest to lowest average valued use, pass through the weighted average value at the mid quantity of acres currently allocated to each use respectively. The slope of each curve represents the marginal value of an additional acre of land allocated to that use. The exact slope is not known, but was approximated in such a way that it intersected the next highest valued use at the margins of current area (1990) allocation, assuming that a land's observed use is its highest valued use. Each curve's intercept was then shifted to produce the 2025 high development scenario's land allocation across uses (see Appendix 4. For current and 2025 land allocation projections). For forested use this represents high intensity short rotation management. This admittedly crude final set of demand curves reflects the free market forces 2025 outcome for land allocation measured in 1995 dollars (See Figure 4; see Appendix 5 for demand curve coefficients).

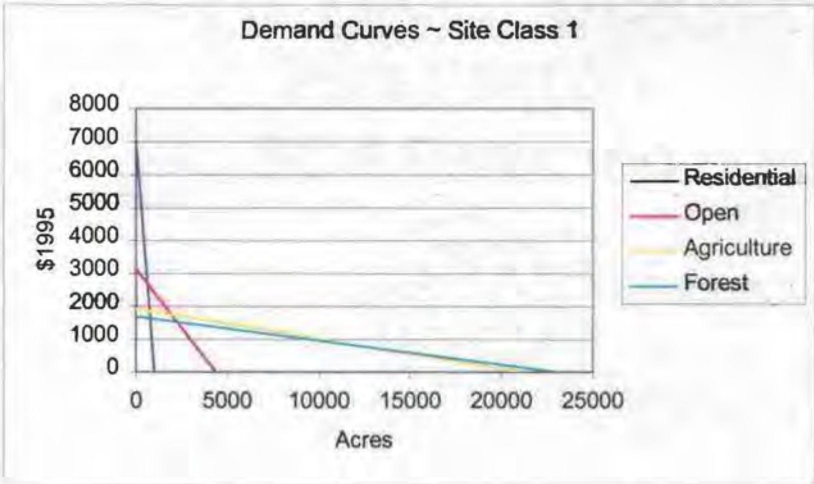


Figure 4. Example Demand Curves

2.2.3 Forest Valuation

To discern the impact on biodiversity and the associated costs brought about by shifts in forest management, values associated with such changes were estimated. These estimates relied on the ISE's 1990 current land-use coverage which depicted four forested (Douglas-fir, *Psuedotsuga menziesii*) land-use age classes; 0 – 40, 40 – 80, 80 – 120, and over 120. Due to the fact that a minimal number of acres was represented by the over 120 years of age class, and also that habitat preference ratings did not discern between the 80 – 120 and the greater than 120 year age class, this class was aggregated with the 80 – 120 year class for modeling purposes.

These three forested land-use classifications represent all possible land allocation opportunities that exist for modeling biodiversity with respect to forest use. Forest practices were not, however, constrained by rotation ages being equal to 40, 80, or 120 years. For this analysis, two management intensity classes (Adams 1998) and seven fully regulated forest rotation ages were examined; 40, 45, 50, 60, 80, 120, and park which is a non-harvested forest, see Table 2. These intensity classes and forest management rotations represent the finest scaled detail this analysis is possible of achieving, given the ISE's original land-use characterizations and species habitat preference ratings. Due to this fact, this project is not able to accurately capture high intensity wildlife habitat management scenarios. Such regimes are targeted at the development of old forest conditions at an earlier age through the use of high intensity thinning strategies. Instead, the broader implications of forest management will be revealed through the steady state analysis of alternative harvest regimes.

	Low Intensity Treatment	High Intensity treatment
Site Prep	X	X
Planting density	400 TPA?	432 TPA
Pre Commercial thinning Year 13	N/A	Thin to 259 TPA
Fertilization year 30	N/A	200 lbs. Nitrogen
Fertilization year 35	N/A	200 lbs. Nitrogen
Commercial thinning Year 35	N/A	Thin to 194 TPA
Final harvest	X	X

Table 2. Management Intensity Classes (Adams 1998).

Each of the forest rotation ages examined represents one of several choices that exist for a landowner when managing forested lands for profit. Private timber companies throughout the Pacific Northwest generally rely on high-intensity, short-rotation forest management. Small private forest holders may or may not choose to mimic the larger corporation's forest practices, and publicly held lands are generally managed for a broader concern for ecological integrity equating to less intensive management and longer rotations. For each of these lands though, there exists the option for management solely to achieve the objective of profit maximization. Consequently, the ISE chose to appropriate all acres of forested use to a forty-year rotation for their 2025 high development scenario.

To represent the opportunity cost of moving from this "market forces" solution to land allocation strategies contributing more to biodiversity, approximate land and timber values (LTV) for each of these alternative forest management regimes were constructed. First, the soil expectation value (SEV) for each of these seven rotation ages and two management intensity classes was calculated. The SEV measure represents the current bare-ground value of all future costs and returns relating to a specific management regime. Planting, site prep, pre-commercial thinning, and fertilization costs were drawn from Shillinger (1998), log and haul costs were based on TAMM estimates (Adams 2000), and returns were calculated based on expected volumes and Benton County specific log pond prices generated by the Oregon State Forest Service (Corgan 1999), see Tables 3 and 4.

Associated costs	Low Intensity Treatment	High Intensity treatment
Site Prep	\$159/acre	\$159/acre
Planting	\$119/acre	\$119/acre
Pre Commercial thinning Year 13	N/A	\$93
Fertilization year 30	N/A	\$75
Fertilization year 35	N/A	\$75
Commercial thinning Year 35	N/A	\$168/MBF
Final harvest	\$168/MBF	\$168/MBF

Table 3. Forest Management Costs (Shillinger 1998).

Rotation length	Pond value ~ adjusted for diameter premiums in accordance with age
40	$580/MBF
45	$580/MBF
50	$620/MBF
60	$620/MBF
80	$620/MBF
120	$690/MBF

Table 4. Log Pond Values

1998 Log pond values scaled by .9699, the change in the producer price index (ppi) of lumber and wood products in the U.S. between the years of 1995 and 1998. The figures illustrate the value per MBF (thousand board feet) of Douglas-fir logs minus harvest and transportation costs. The variability between rotation ages represents the instigated quality premiums.

A detailed soil's coverage and King's fifty-year site index map were obtained from the State Soil Geographic Data Base (STATSGO) map from the National Resources Conservation Service (NRCS). This site index map was combined with a reclassed soils and slope coverage to determine soil-slope-site class specific site indices for Douglas-fir forests of the region. These site indices ranged from 112 to 122 and roughly corresponded with Oregon's Forest Inventory and Analysis (FIA) average site index for Benton County forested plots of 121.

Expected volumes and log diameters associated with each of the management regimes and soil-slope-site classes were ascertained through the use of DFSIM, a growth and yield model developed specifically for Pacific Northwest Douglas-fir forests (Ritchie 1999). Alternative growth and yield models exist, most notably ORGANON, but for this application DFSIM seemed most appropriate based on the feasibility of its projected volumes for rotations longer than 80 years.

Predicted thinning and harvest volumes, as well as log diameter information, was drawn from DFSIM. Based on these log diameters and log pond values, a generalized quality premium was constructed utilizing log grades characterized by Bell and Dilworth (1988). Based on these quality premiums, harvest volumes, log prices, and costs, SEVs and LTVs were calculated for each management regime. These measures were calculated with an interest rate of seven percent, the average real AAA bond rate over the last decade. The formula used to calculate SEV is depicted by Equation 5, estimated SEVs for each management regime are illustrated by Table 5, and the estimated changes in LTV as forested regimes are shifted from the profit maximizing 40 year rotation to longer rotations are depicted by Table 6. (Note that these LTV opportunity costs were calculated utilizing an area control approach to account for forest conversions).

$$SEV = \left[- PC - \frac{PCT}{(1.07)^{13}} - \frac{FE}{(1.07)^{30}} - \frac{(FE + LH*Q)}{(1.07)^{35}} + \frac{PQ*TH}{(1.07)^{35}} + \frac{PQ*H - LH*Q}{(1.07)^{t}}\right] * \left[1 + \frac{1}{(1.07)^{t} - 1}\right] \qquad (5)$$

Where:

SEV	=	Soil expectation value
PC	=	Planting and site prep costs
PCT	=	Pre-commercial thinning cost
FE	=	Fertilization cost
PQ	=	Revenue/MBF timber, scaled with a log diameter quality premium
TH	=	Thinning volume harvested (MBF)
LH	=	Log and Hauling cost/MBF
H	=	Final harvest volume (MBF)
t	=	Rotation age

Intensity	Site Index	Site class	40	45	50	60	80	120
Low	122	1	$363	$343	$338	$162	-$109	-$252.5
Low	122	2	$363	$343	$338	$162	-$109	-$252.5
Low	112	3	$171	$179	$190	$72	-$137	-$255.9
Low	112	4	$171	$179	$190	$72	-$137	-$255.9
Low	119	5	$315	$300	$298	$137	-$117	-$253.5
Low	114	6	$199	$204	$214	$87	-$132	-$255.2
High	122	1	$605	$588	$575	$368	$48	-$43.4
High	122	2	$605	$588	$575	$368	$48	-$43.4
High	112	3	$372	$378	$376	$201	-$88	-$211.3
High	112	4	$372	$378	$376	$201	-$88	-$211.3
High	119	5	$549	$536	$525	$326	$16	-$81.5
High	114	6	$403	$406	$403	$222	-$72	-$194.4

Table 5. Soil Expectation Values

Site Index	45	50	60	80	120	Park
122	$294	$299	$470	$1739	$2873	$4248
112	$201	$148	$226	$1314	$2274	$3505
119	$272	$267	$419	$1639	$2727	$4065
114	$213	$166	$255	$1372	$2360	$3618

Table 6. Land and Timber Values

Ultimately, the low intensity management scenario for forest use was dropped, as this management strategy failed to produce higher SEVs or LTVs for any forest rotation length analyzed, than that of any of the high intensity management regimes. Changes in LTV, depicted by Table 6, were then utilized to reduce the market value for lands allocated to alternative forest management regimes. These changes in LTV measures represented the opportunity (conversion) cost of shifting land from the profit maximizing forty-year rotation, to a longer rotation length.

3.0 RESULTS

In developing a marginal cost curve for biodiversity, the opportunity cost of reallocating land from its highest valued use to a new use that has a higher biodiversity value but lower market value is measured against gains in the biodiversity index (Montgomery 1999). This is accomplished by developing an objective function that maximizes land value and the expected biodiversity measure simultaneously (Equation 6).

$$TV = \sum_{j=1}^{6} \sum_{k=1}^{4} \left[\int_{q=0}^{Qkj} (\alpha_{kj} + \beta_{kj}\, q)\, dq \right] - \sum_{j=1}^{6} \sum_{m=1}^{6} [C_{jm} * Q_{jm}] + B * \left(\sum_{s=1}^{196} V_s(P_s) * W_s\right) \qquad (6)$$

Where:

TV	= Total value of the Muddy Creek Watershed
k	= Land-use (residential, open, agriculture, seven forest alternatives)
j	= Slope and soil-based site class
m	= Forest management regime
α_{kj}	= Demand curve intercept
β_{kj}	= Estimated slope of the demand curve
C_{kj}	= LTV conversion cost
B	= Biodiversity scaling weight
V_s	= Species viability
P_s	= Population index (see Equation 3)
W_s	= Diversity weight

Equation 6 represents a total value index of the Muddy Creek Watershed, represented by the sum of the predicted land and biodiversity values. The first expression in the equation denotes the total market value of the watershed, given a particular configuration of uses (k) in site classes (j). The biodiversity value, the second expression in the objective function, is the expected biodiversity measure previously discussed (see Equations 2 - 4), scaled by (B).

The demand curves were calibrated so that maximizing this objective function without regard to biodiversity (biodiversity weight (B) = 0) yielded the ISE's high development scenario land allocation. This represents the worst-case scenario for biodiversity in the Muddy Creek Watershed. Similarly, dismissing land value from the objective function yields the optimal arrangement of habitats that maximize expected biodiversity. These two scenarios represent the extreme outcomes for the management of biodiversity.

Utilizing the non-linear optimization software package, GAMS MINOS5, intermediate points along the marginal cost curve for biodiversity were identified by solving Equation (6) repeatedly, incrementally increasing the biodiversity weight (B) (See Appendix 6. for an example GAMS code). By varying (B), and simulating landowner supply responses, biodiversity demand was shifted revealing a marginal cost curve for wildlife diversity.

The marginal cost curve for biodiversity, illustrated by figure 5, depicts all possible wildlife diversity outcomes for this index and future land management opportunities. The expected diversity index ranges from a maximum value of 310.18 to a minimum index value is 296.19 representing the expected biodiversity yielded by the ISE's high development "free market forces" scenario. Current land-use configurations yield a biodiversity index of 307.64. At this level of biodiversity protection, an additional increment in expected diversity would cost landowners nearly ten million dollars. The total cost of moving from no biological protection (high development scenario) to this level of protection is given as the area under the marginal cost curve, or the integral from a biodiversity index of 296.19 to 307.64, approximately 22.5 million dollars.

Maintaining the current landscape into 2025 is an inefficient solution to the land allocation problem. To discern this inefficiency, a total opportunity cost curve, representing the accumulated present value of foregone future land rents, was constructed (see Appendix 7). The current landscape yields a biodiversity index of 307.64, representing a predicted total opportunity cost of 56.8 million dollars. For a similar expenditure on biodiversity protection land managers could, however, come within a fraction of a biodiversity index point of the maximum attainable diversity for this watershed.

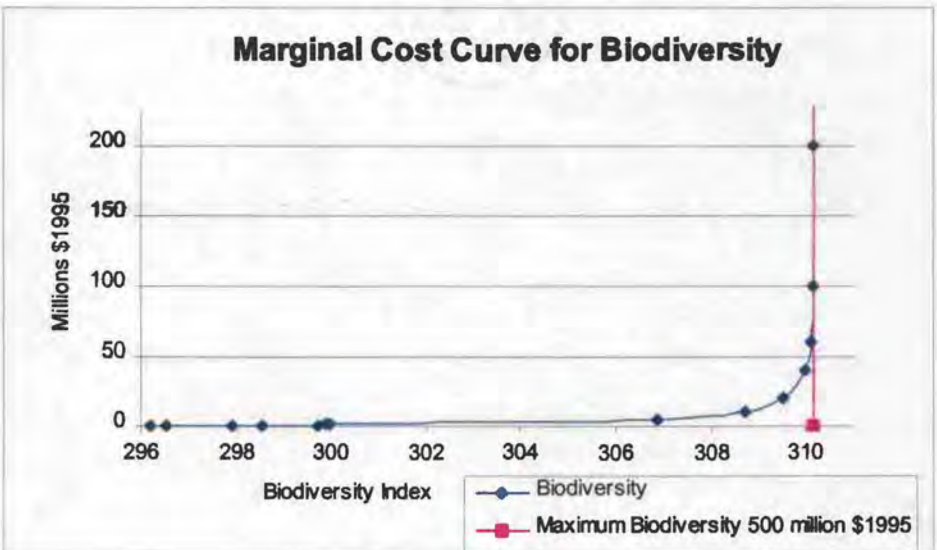


Figure 5. Marginal Cost Curve for Biodiversity

In determining the likely impacts of forest management on the biodiversity index, management regimes were tracked throughout the land allocation optimization process. From a modeling standpoint, each acre that is allocated to each of the forest rotations respectively is portioned into one of three habitat associations; 0-40, 40-80, or 80-120 year-old forests. The sixty year rotation for example, assigns two-thirds of its total area to the 0-40 habitat association, whereas one-third of its area would be contributed to the 40-80 classification. The park scenario allocates one hundred percent of its acres to the 80-129 land-use class.

The resulting forest allocations range from all forested acres being allotted to the forty-year rotation under the free market forces solution, to approximately 4,000 acres allocated to the forty-year management regime and the remaining 17,000 forested acres being deemed park for the maximum attainable biodiversity solution. Intermediate regimes, management rotation lengths of 80 and 120, are not favored over the park scenario for their contribution to the biodiversity index, given an associated gain in LTV (see Figure 6).

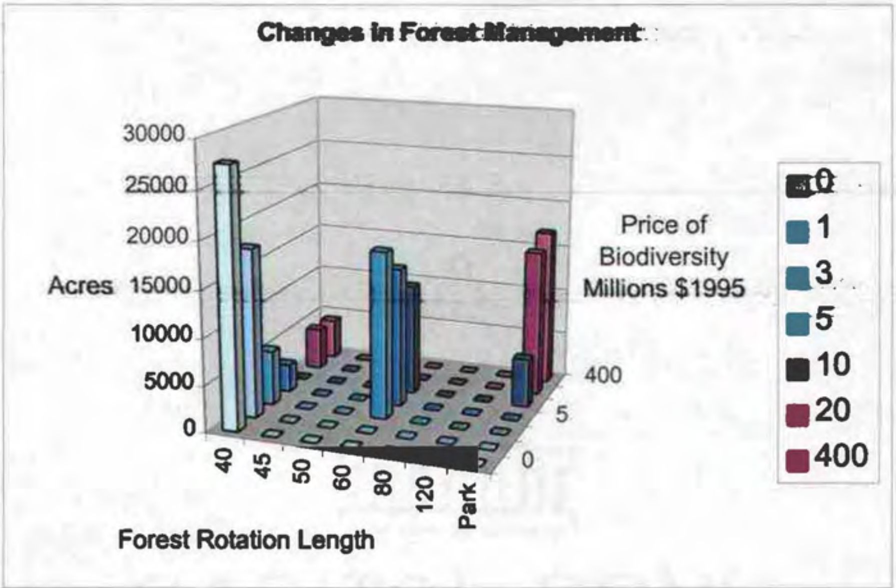


Figure 6. Changes in Forest Management

4.0 SUPPLEMENTARY ANALYSIS

The marginal cost curve for biodiversity represents all possible efficient land allocation opportunities in the Muddy Creek Watershed when biodiversity is of concern. As such, it is a useful construct to gauge the implications of management strategies targeting imperiled species alone, and the efficiency of land allocations supported by the ISE's possible futures project.

4.1 A Marginal Cost Curve for Imperiled Species

The endangerment of native species has been of great national concern over recent decades. Such concern led to adoption of the Endangered Species Act, and has ultimately reshaped federal and state land management planning. Emphasis, and often times priority, is given to those management strategies targeting imperiled species.

A marginal cost curve for imperiled species conveys information relating to the specific needs and preferences of such species. The curve represents land configurations yielding a desired level of imperiled species protection at the minimum cost. By tracking the watershed's total biodiversity as imperiled species diversity is specifically optimized, the implications of such management tactics are revealed.

Seven imperiled species are thought to exist in Muddy Creek Watershed, see Table 7 (Csuti et al. 1997b, Oregon Natural Heritage Program 1998). These species represent about three and a half percent of the total number of species present in the area, and do not include species that have been introduced or locally extirpated.

Oregon Nature Conservancy's IUCN endangerment rating	**Scientific Name**	**Common Name**
Imperiled	Branta canadensis	Canada Goose
Imperiled	Brachyramphus Marmoratus	Marbled Murrelet
Imperiled	Athene cunicularia	Burrowing Owl
Imperiled	Ammodramus Savannarum	Grasshopper Sparrow
Imperiled	Martes pennanti	Fisher
Imperiled	Clemmys maormorata	Western Pond Turtle
Imperiled	Chrysemys picta	Painted Turtle

Table 7. Imperiled Species

In order to compare optimal land management for overall biodiversity protection to optimal management for imperiled species only, Equation 6 was again solved repeatedly for a variety of values for the biodiversity weight (B). For this analysis, the expected diversity measure, E(D), Equation 4, was replaced with an imperiled species diversity measure, E(I), Equation 7. This formulation of diversity in effect maximized the expected species richness of all imperiled species, i.

$$E(D) = \sum_{s=1}^{196} V_s(P_s) * W_s \qquad (4)$$

$$E(I) = \sum_{i=1}^{7} V_i(P_i) \qquad (7)$$

As the implied price paid for biodiversity increases to favor imperiled populations, and land is allocated to meet the specific needs of these species, overall biodiversity actually declines steadily. Solutions closest to the free market forces solution, a broader diversity of land uses, yield the highest overall values for expected diversity, while land allocations favoring imperiled species alone devote lands to the agriculture and park uses exclusively. Figure 7 contrasts these gains in imperiled species diversity, E(I), as lands are allocated to meet the specific needs of such species, with declines in overall expected diversity E(D) (see Appendix 7 for the marginal cost curve for imperiled species diversity). The population index values for each of the seven imperiled species follows in Figure 8.

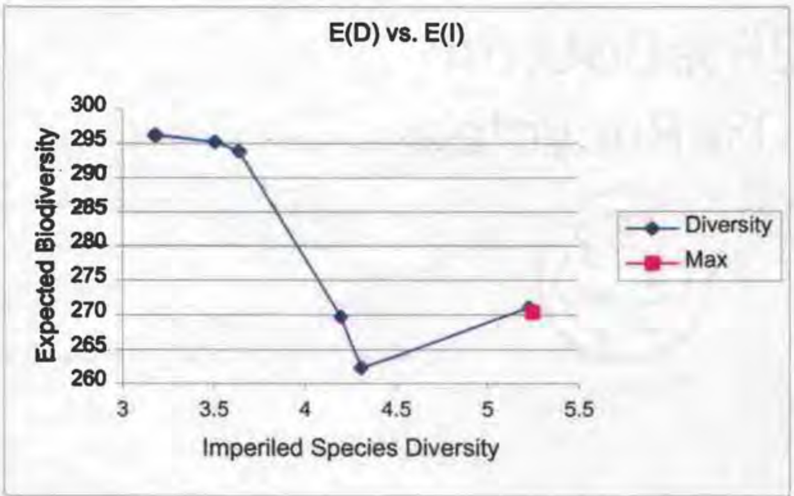


Figure 7. Expected Biodiversity vs. Imperiled Diversity.

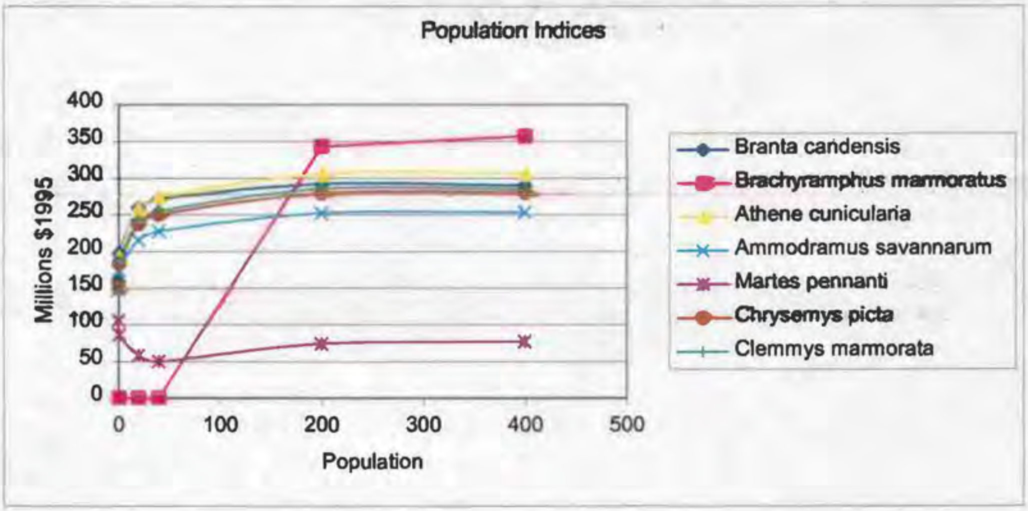


Figure 8. Imperiled Species Population Indices

4.2 Inefficiencies in Land Use Planning

The ISE has been steadily producing and analyzing spatial data-sets of western Oregon. The Muddy Creek Watershed is one of the areas this team of landscape designers has devoted much time to, and is in fact the original source of much of the data utilized by this project. As part of their efforts, a series of possible futures for land-use in the watershed were constructed based on trends in use and emphasis in land management planning goals.

The possible futures project developed five plausible land-use scenarios for the year 2025: current trend, high development, moderate development, high conservation, and moderate conservation. These landscapes were constructed by a team of landscape designers relying on information provided by community representatives, biologists, ecologists, land use planners, and population dynamics modelers. The underlying objective of the project was to discern the implications of these future landscapes from the perspectives of water quality and wildlife biodiversity; indicators of ecological stability.

The high conservation landscape was constructed by incorporating three primary assumptions about land use into forecasting; limited residential expansion, the introduction of windbreaks, hedgerows, and streamside buffers, and increased rotation length in both hybrid poplar plantations and managed Douglas-fir forests. This predicted landscape represents the ISE's best possible scenario for biodiversity. The fact that the possible futures study did not incorporate specific indicators for biodiversity into their modeling procedures, instead relying on group consensus of "what's best" given all their objectives, suggests that the projected landscape might be an inefficient solution to the land allocation problem. To examine the biological contribution of the "Possible Futures for the Muddy Creek Watershed, Benton County, Oregon" (Hulse et al. 1997) high conservation landscape, and the resulting efficiency of such solutions, the projected landscape's allocation of acres across land uses was utilized to develop measures of expected diversity and total land value relying on the previously discussed solution methodologies. Inherent to this framework, expected population estimates were simultaneously forecasted with expected diversity.

The ISE's high conservation land allocation yielded a biodiversity index value of 308.13. This represents a total opportunity cost or reduction in possible future land rents of $71.5 million dollars, and is an inefficient solution to this land allocation problem. The biodiversity index shows marginal gains in wildlife diversity over the current landscape, but as is illustrated by Figure 9, local land managers could come within a fraction of the maximum attainable biodiversity for a similar expenditure on biodiversity.

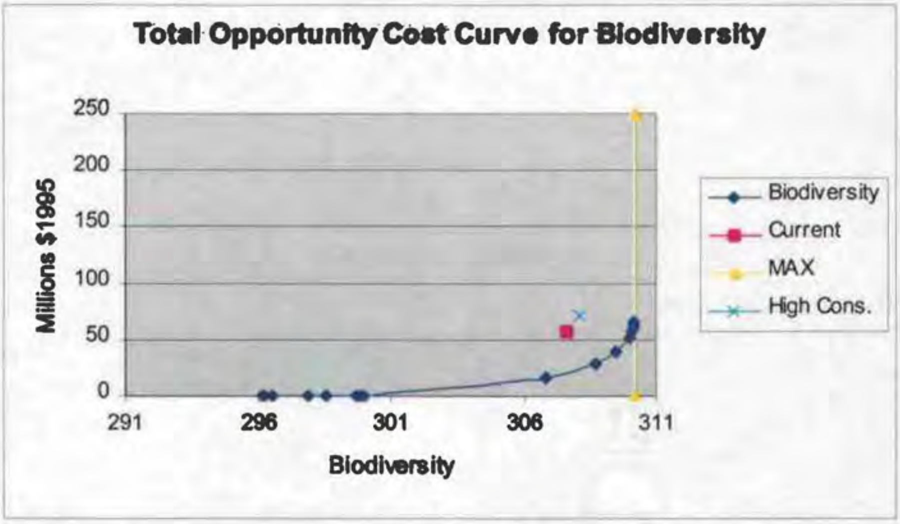


Figure 9. ISE's High Conservation Biodiversity

Five of the seven imperiled species actually do better in the current configuration of habitats over the high conservation's land-use allocations. The Marbled Murrelet, whose population index more than doubled, and the Fisher, were the two species whose population indices rose given the ISE's high conservation scenario. The impact on less endangered species was variable, and can be viewed in Appendix 8, which depicts population estimates for all 196 species under a variety of land-use treatments.

5.0 DISCUSSION

While the wildlife biodiversity index used by Montgomery yields a number of useful results and land management implications for the Muddy Creek Watershed, it is limited in the following ways. The diversity index does not capture species spatial preferences including habitat contiguity, edge effects, core area requirements, or neighboring habitat preference. As such, the index does not prescribe plot-based land prescriptions, and instead suggests larger scale habitat allocations by jointly considering all species' habitat preferences and uniqueness ratings. These habitat allocations suggest the broader management implications when biodiversity is of concern, relying heavily on the biologist's species habitat preference ratings, and the demand curves approximated by this project. These limitations coupled with shortcomings in empirical estimation of land values could help to explain some of the discrepancies between the ISE's high conservation contribution to biodiversity and this model's solution. Further disparities could be in part due to the fact that this study fails to include spatial considerations, likely rendering some results infeasible.

The marginal cost curve for biodiversity depicted by figure 5, represents the full range of management options for the protection of biodiversity. The shape of this curve, and the underlying land allocations, have a number of interesting management implications relative to the watershed. To retain the current level of biodiversity protection into 2025, which has an associated biodiversity value of 307.64, would require a one-time current payment to landowners of 22.5 million dollars.

The marginal cost of an additional unit of biodiversity over the current level of protection is nearly ten million dollars. And capturing the final increment in biodiversity, moving from an expected diversity measure of 309 to 310, has an associated cost of 400 million dollars. (Payments like these could be viewed as a compensatory reimbursements or necessary tax incentives, policy instruments designed to account for the incurred opportunity costs to landowners of biological protection). This leads to a discussion of the marginal gains associated with increasingly higher amounts paid for biodiversity. For roughly a sixty million dollar expenditure on biodiversity, local land managers could come very close to the maximum attainable biodiversity solution for this watershed. To capture the final increments in the biodiversity index though, managers would have to pay nearly seven times this much, primarily reallocating the acres that are currently used for residential purposes to uses more suitable for biodiversity. In addition, the maximum biodiversity arrangement of land uses brings a fractional change in the population indices of species over other biodiversity favoring scenarios, see Appendix 8, and is a questionable use of resources for local land managers. Montgomery et al. (1999), Montgomery et al. (1994), and Ando et al.(1998) report similar findings.

Land allocations favoring imperiled or critically imperiled species have drastic effects on the overall expected diversity of the region. All seven of these species favor either old forest or agriculturally-based habitats. Land allocations scenarios favoring these species thus focus on either park or agriculture uses, drastically impacting the overall biodiversity index for all species that favor a much broader allocation between uses. Such results indicate the need to consider a more comprehensive set of species and their related needs when addressing land-use allocations.

The ISE's high conservation landscape results in a number of interesting implications from a biodiversity viewpoint. Recall that the ISE's original charge was to develop a set of feasible land allocations for the year 2025, with the high conservation scenario's emphasis being on improved water quality and biodiversity-friendly land-use allocations. The team considered a broader host of objectives than biodiversity and land value when formulating the high conservation landscape. The depicted future land-use map yields a modest gain in the biodiversity index, from 307.64 to 308.13, and five of the seven imperiled species actual favor the current configuration of land uses over ISE's suggested landscape.

The final point worth mentioning with regards to this future arrangement of habitats, is the ISE's extension of forest rotations to eighty years and the addition of a number of forest reserve sites to seemingly improve biodiversity values. Data generated based on the biodiversity index of this study indicates that larger gains in overall biodiversity simply are not brought about by increasing forest rotation lengths. In fact, most species favor either young or old forests, indicating that local managers would be better served by allowing some degree of intensive forest management, while trying to procure as many forest reserves as possible. The data does not support the idea that eighty-year rotations are better than forty-year rotations when biodiversity is of concern. It does certainly suggest though, that the no harvest 120-year-old or older forest is most favored by the populations representative of this study.

Overall, forest management plays an integral role in the protection of biodiversity. Expected wildlife diversity benefits more from no harvest or natural forest reserve areas than from simply lengthening the profit maximizing rotation length beyond 40 years. In fact, based on the species habitat preference ratings, only eight of the 196 species modeled actually prefer the 40 – 80 year Douglas-fir land-use allocation to other uses. And, all eight of the species find either the neighboring 0 – 40 or 80 - 120 plus Douglas-fir habitat categories nearly as appealing.

6.0 CONCLUSION

This project adds to a growing base of literature, which at its core, enhances our understanding of how the extinction rates common today can be lessened in the future through efficient land management strategies. In spite of its limitations, the framework utilized for modeling biodiversity in this project has produced a number of useful results. Key results being: 1) the illustration of the importance of protecting and developing old-growth forest conditions, and 2) the demonstration of the pitfalls of considering only imperiled or critically imperiled species in conservation land-use planning.

Incorporating this biodiversity index into spatial analyses is a logical next stage in today's developmental frameworks for modeling wildlife diversity. Currently, the data needed to construct a useful model of this caliber is of limited availability. We are, however, slowly bridging the gap of our understanding so that at some point in the near future, both the multi-species biodiversity studies, like the one presented here, and single species models incorporating a species preference for multiple habitats and the relationships that exists between and amongst these habitats, will be united.

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APPENDICES

Appendix 1.

IUCN imperilment ranks and diversity weights

		IUCN Rank	Diversity Weight
Ambystoma	gracile	5	1.429
Ambystoma	macrodactylum	5	1.429
Aneides	ferreus	5	1.25
Ensatina	eschscholtzii	5	1.25
Plethodon	dunni	5	1
Plethodon	vehiculum	5	1
Taricha	granulosa	5	1.25
Dicamptodon	tenebrosus	4	1.25
Ascaphus	truei	4	2
Pseudacris	regilla	5	2
Rana	aurora	4	1.25
Ardea	herodias	5	2.684
Butorides	virescens	5	2.684
Branta	canadensis	2	2.684
Aix	sponsa	5	2.684
Anas	platyrhynchos	5	2.318
Lophodytes	cucullatus	5	2.684
Cathartes	aura	5	2.684
Pandion	haliaetus	5	2.684
Elanus	leucurus	3	2.04
Haliaeetus	leucocephalus	4	2.04
Circus	cyaneus	5	2.04
Accipiter	striatus	5	1.821
Accipiter	cooperii	5	1.821
Accipiter	gentilis	3	1.821
Buteo	jamaicensis	5	2.04
Aquila	chrysaetos	5	2.04
Falco	sparverius	5	2.04
Dendragapus	obscurus	5	2.429
Bonasa	umbellus	5	2.429
Oreortyx	pictus	4	2.429
Charadrius	vociferus	5	2.833
Gallinago	gallinago	5	2.55
Brachyramphus	marmoratus	2	2.833
Columba	fasciata	5	2.684
Zenaida	macroura	5	3
Tyto	alba	5	3
Otus	kennicottii	5	2.125
Bubo	virginianus	5	2.125
Glaucidium	gnoma	4	2.125
Athene	cunicularia	2	2.125
Strix	occidentalis	3	1.962
Strix	varia	5	1.962
Asio	otus	4	1.962
Asio	flammeus	4	1.962
Aegolius	acadicus	4	2.125
Chordeiles	minor	5	3.4
Chaetura	vauxi	5	3.4

		IUCN Rank	Diversity Weight
Calypte	anna	4	3
Selasphorus	rufus	5	3
Melanerpes	lewis	4	2.318
Melanerpes	formicivorus	3	2.318
Sphyrapicus	ruber	4	2.55
Picoides	pubescens	4	2.318
Picoides	villosus	4	2.318
Colaptes	auratus	5	2.55
Dryocopus	pileatus	4	2.55
Contopus	borealis	4	1.244
Contopus	sordidulus	4	1.244
Empidonax	traillii	4	1.214
Empidonax	hammondii	4	1.214
Empidonax	difficilis	4	1.214
Tyrannus	verticalis	5	1.308
Eremophila	alpestris	5	1.417
Progne	subis	3	1.275
Tachycineta	bicolor	5	1.214
Tachycineta	thalassina	5	1.214
Hirundo	pyrrhonota	5	1.214
Hirundo	rustica	5	1.214
Cyanocitta	stelleri	5	1.308
Aphelocoma	californica	5	1.308
Corvus	brachyrhynchos	5	1.244
Corvus	corax	4	1.244
Parus	atricapillus	5	1.342
Parus	rufescens	5	1.342
Psaltriparus	minimus	5	1.417
Sitta	canadensis	5	1.342
Sitta	carolinensis	4	1.342
Certhia	americana	4	1.417
Thryomanes	bewickii	4	1.308
Troglodytes	aedon	4	1.244
Troglodytes	troglodytes	4	1.244
Regulus	satrapa	4	1.417
Sialia	mexicana	4	1.275
Catharus	ustulatus	5	1.275
Turdus	migratorius	5	1.275
Ixoreus	naevius	4	1.275
Chamaea	fasciata	5	1.417
Bombycilla	cedrorum	5	1.417
Vireo	solitarius	4	1.308
Vireo	huttoni	4	1.308
Vireo	gilvus	5	1.308
Vermivora	celata	5	1.214
Dendroica	petechia	4	1.109
Dendroica	coronata	5	1.109
Dendroica	nigrescens	5	1.109
Dendroica	occidentalis	4	1.109

		IUCN Rank	Diversity Weight
Oporornis	tolmiei	4	1.214
Geothlypis	trichas	5	1.214
Wilsonia	pusilla	5	1.214
Icteria	virens	4	1.214
Piranga	ludoviciana	5	1.417
Pheucticus	melanocephalus	5	1
Passerina	amoena	4	1
Pipilo	maculatus	4	1
Spizella	passerina	4	1
Poecetes	gramineus	4	1
Passerculus	sandwichensis	5	1
Ammodramus	savannarum	2	1
Melospiza	melodia	5	1
Zonotrichia	leucophrys	5	1
Junco	hyemalis	5	1
Agelaius	phoeniceus	5	1
Sturnella	neglecta	4	1
Euphagus	cyanocephalus	5	1
Molothrus	ater	5	1
Icterus	bullockii	4	1
Carpodacus	purpureus	4	1.214
Carpodacus	mexicanus	5	1.214
Loxia	curvirostra	4	1.275
Carduelis	pinus	5	1.186
Carduelis	psaltria	4	1.186
Carduelis	tristis	4	1.186
Coccothraustes	vespertinus	5	1.275
Sorex	vagrans	4	1.714
Sorex	pacificus	3	1.714
Sorex	bendirii	4	1.714
Sorex	trowbridgii	4	1.714
Sorex	sonomae	5	1.714
Neurotrichus	gibbsii	4	2.182
Scapanus	townsendii	4	1.846
Scapanus	orarius	5	1.846
Myotis	lucifugus	4	1.263
Myotis	yumanensis	3	1.263
Myotis	evotis	3	1.263
Myotis	thysanodes	3	1.263
Myotis	volans	3	1.263
Myotis	californicus	4	1.263
Lasionycteris	noctivagans	4	1.846
Eptesicus	fuscus	4	1.846
Lasiurus	cinereus	4	1.846
Plecotus	townsendii	4	1.846
Antrozous	pallidus	3	1.846
Sylvilagus	bachmani	5	2.182
Lepus	americanus	4	2.182
Lepus	californicus	4	2.182

		IUCN Rank	Diversity Weight
Aplodontia	rufa	4	1.714
Tamias	townsendii	4	1.412
Spermophilus	beecheyi	5	1.412
Sciurus	griseus	4	1.412
Tamiasciurus	douglasii	5	1.5
Glaucomys	sabrinus	4	1.5
Thomomys	mazama	4	1.5
Thomomys	bulbivorus	5	1.5
Castor	canadensis	4	1.714
Peromyscus	maniculatus	4	1.2
Neotoma	fuscipes	5	1.091
Neotoma	cinerea	5	1.091
Clethrionomys	californicus	4	1.2
Phenacomys	albipes	3	1.091
Phenacomys	longicaudus	4	1.091
Microtus	townsendii	4	1
Microtus	longicaudus	5	1
Microtus	oregoni	4	1
Microtus	canicaudus	5	1
Zapus	trinotatus	4	1.714
Erethizon	dorsatum	5	1.714
Canis	latrans	5	1.412
Vulpes	vulpes	4	1.6
Urocyon	cinereoargenteus	4	1.6
Ursus	americanus	4	1.714
Procyon	lotor	5	2
Martes	americana	3	1.263
Martes	pennanti	2	1.263
Mustela	erminea	5	1.2
Mustela	frenata	5	1.2
Spilogale	gracilis	4	1.412
Mephitis	mephitis	5	1.412
Felis	concolor	4	1.5
Lynx	rufus	4	1.5
Cervus	elaphus	5	2.667
Odocoileus	hemionus	5	2.4
Chrysemys	picta	2	3.5
Clemmys	marmorata	2	3.5
Elgaria	coerulea	5	1.556
Elgaria	multicarinata	5	1.556
Sceloporus	occidentalis	5	2
Eumeces	skiltonianus	5	2
Charina	bottae	4	2
Coluber	constrictor	4	1.167
Contia	tenuis	3	1.167
Diadophis	punctatus	4	1.167
Pituophis	catenifer	5	1.167
Thamnophis	ordinoides	5	1
Thamnophis	sirtalis	5	1
Crotalus	viridis	4	2

Appendix 2.

Species habitat preference ratings

		For 0-40	For 40-80	For 80 +	Open	Agr	Res
Ambystoma	gracile	2	9	10	5.83	0.00	0
Ambystoma	macrodactylum	3	3	3	5.36	3.81	3
Aneides	ferreus	2	5	8	0.86	0.00	0
Ensatina	eschscholtzii	6	10	10	6.87	0.23	0
Plethodon	dunni	2	10	10	2.87	0.00	0
Plethodon	vehiculum	3	10	10	2.01	0.00	0
Taricha	granulosa	6	9	10	8.27	1.85	0
Dicamptodon	tenebrosus	2	10	10	4.08	0.00	0
Ascaphus	truei	0	7	9	2.16	0.00	0
Pseudacris	regilla	3	4	4	7.27	3.40	4
Rana	aurora	1	4	4	3.20	0.95	0
Ardea	herodias	0	3	4	5.70	1.67	1
Butorides	virescens	5	8	8	6.95	0.00	0
Branta	canadensis	0	0	0	0.05	3.02	3
Aix	sponsa	0	0	0	6.74	0.00	0
Anas	platyrhynchos	0	0	0	0.00	4.59	0
Lophodytes	cucullatus	0	1	2	6.02	0.00	0
Cathartes	aura	10	4	7	7.48	3.89	0
Pandion	haliaetus	0	0	2	0.00	0.00	2
Elanus	leucurus	0	0	0	1.00	2.44	0
Haliaeetus	leucocephalus	0	2	6	0.75	0.00	0
Circus	cyaneus	2	0	0	0.30	2.81	0
Accipiter	striatus	4	10	8	5.37	0.92	1
Accipiter	cooperii	3	9	8	7.78	0.70	3
Accipiter	gentilis	0	4	5	0.00	0.00	0
Buteo	jamaicensis	5	3	4	6.65	3.11	2
Aquila	chrysaetos	2	0	1	0.28	0.46	0
Falco	sparverius	3	0	0	3.74	5.15	8
Dendragapus	obscurus	6	9	10	2.44	0.00	0
Bonasa	umbellus	6	7	6	7.25	0.00	0
Oreortyx	pictus	8	0	0	5.01	0.92	0
Charadrius	vociferus	0	0	0	0.00	1.01	5
Gallinago	gallinago	0	0	0	0.00	0.22	0
Brachyramph	marmoratus	0	0	1	0.00	0.00	0
Columba	fasciata	4	7	6	4.64	0.00	0
Zenaida	macroura	8	0	0	3.36	6.04	5
Tyto	alba	0	0	1	1.04	5.04	10
Otus	kennicottii	5	8	9	8.59	0.00	3
Bubo	virginianus	4	8	10	8.87	3.65	3
Glaucidium	gnoma	3	9	10	3.46	0.00	0
Athene	cunicularia	0	0	0	0.00	0.22	0
Strix	occidentalis	0	5	10	0.00	0.00	0
Strix	varia	0	5	9	7.15	0.00	0
Asio	otus	4	4	2	5.23	0.00	0
Asio	flammeus	0	0	0	0.00	0.86	0

		For 0-40	For 40-80	For 80 +	Open	Agr	Res
Aegolius	acadicus	2	9	10	5.34	0.00	0
Chordeiles	minor	6	0	0	0.05	0.92	0
Chaetura	vauxi	0	0	10	0.00	0.00	10
Calypte	anna	0	0	0	7.03	0.00	5
Selasphorus	rufus	10	8	7	7.57	0.00	6
Melanerpes	lewis	0	0	0	2.62	0.00	0
Melanerpes	formicivorus	0	0	0	3.19	0.00	0
Sphyrapicus	ruber	2	7	7	6.52	0.00	4
Picoides	pubescens	2	0	0	8.52	0.00	4
Picoides	villosus	2	8	10	5.51	0.00	0
Colaptes	auratus	3	4	4	5.09	1.58	9
Dryocopus	pileatus	2	8	10	3.29	0.00	0
Contopus	borealis	4	8	10	0.86	0.00	0
Contopus	sordidulus	3	2	2	7.93	0.00	5
Empidonax	traillii	8	0	0	0.14	0.00	0
Empidonax	hammondii	7	10	6	0.43	0.00	0
Empidonax	difficilis	2	10	10	5.89	0.00	1
Tyrannus	verticalis	0	0	0	0.21	0.68	0
Eremophila	alpestris	0	0	0	0.00	0.69	0
Progne	subis	1	0	4	0.00	0.00	0
Tachycineta	bicolor	4	2	3	5.97	0.65	0
Tachycineta	thalassina	7	0	0	0.23	1.08	9
Hirundo	pyrrhonota	0	0	0	0.00	0.00	6
Hirundo	rustica	0	0	0	0.00	1.30	10
Cyanocitta	stelleri	8	9	10	3.02	0.00	0
Aphelocoma	californica	0	0	0	7.54	0.52	10
Corvus	brachyrhynchos	1	0	0	2.22	4.50	10
Corvus	corax	2	7	10	2.16	0.86	0
Parus	atricapillus	2	1	1	9.58	0.00	8
Parus	rufescens	5	10	10	1.30	0.00	2
Psaltriparus	minimus	9	0	0	7.89	0.48	7
Sitta	canadensis	3	10	10	2.47	0.00	2
Sitta	carolinensis	0	0	0	6.29	0.00	1
Certhia	americana	1	8	10	5.77	0.00	1
Thryomanes	bewickii	7	1	0	7.64	0.23	2
Troglodytes	aedon	7	1	1	6.68	0.23	7
Troglodytes	troglodytes	7	9	10	3.89	0.00	0
Regulus	satrapa	3	9	10	3.46	0.00	0
Sialia	mexicana	4	0	0	2.27	2.03	2
Catharus	ustulatus	8	10	9	4.67	0.00	0
Turdus	migratorius	8	6	5	7.74	3.91	8
Ixoreus	naevius	0	8	10	2.59	0.00	0
Chamaea	fasciata	7	0	0	2.13	0.00	0
Bombycilla	cedrorum	3	0	0	4.88	0.48	6
Vireo	solitarius	2	3	2	7.15	0.00	0

		For 0-40	For 40-80	For 80 +	Open	Agr	Res
Vireo	huttoni	1	8	6	6.80	0.00	0
Vireo	gilvus	1	0	0	5.21	0.00	2
Vermivora	celata	7	0	0	8.95	0.00	1
Dendroica	petechia	0	0	0	0.94	0.00	0
Dendroica	coronata	0	6	7	1.73	0.00	0
Dendroica	nigrescens	2	3	2	7.29	0.00	0
Dendroica	occidentalis	2	10	10	2.59	0.00	0
Oporornis	tolmiei	10	0	0	3.62	0.00	0
Geothlypis	trichas	0	0	0	1.18	1.03	0
Wilsonia	pusilla	9	8	0	4.52	0.00	0
Icteria	virens	0	0	0	0.90	0.00	0
Piranga	ludoviciana	2	8	7	4.95	0.00	0
Pheucticus	melanocephal	1	5	5	7.71	0.00	0
Pipilo	maculatus	6	1	0	7.35	0.92	5
Spizella	passerina	2	0	0	4.82	1.15	3
Poecetes	gramineus	0	0	0	0.37	1.34	0
Passerculus	sandwichensis	0	0	0	0.37	5.27	0
Ammodramu	savannarum	0	0	0	0.14	0.22	0
Melospiza	melodia	7	2	1	5.08	2.26	6
Zonotrichia	leucophrys	4	0	0	2.28	1.40	3
Junco	hyemalis	6	8	4	4.33	1.15	2
Agelaius	phoeniceus	0	0	0	0.48	3.94	0
Sturnella	neglecta	0	0	0	0.55	2.63	0
Euphagus	cyanocephalus	0	0	0	0.99	4.20	9
Molothrus	ater	5	3	2	5.73	3.04	4
Icterus	bullockii	1	0	0	2.32	0.00	2
Carpodacus	purpureus	6	10	8	6.52	0.00	0
Carpodacus	mexicanus	0	0	0	4.63	1.41	10
Loxia	curvirostra	1	9	9	2.59	0.00	0
Carduelis	pinus	5	8	9	1.30	0.00	0
Carduelis	psaltria	0	0	0	4.29	1.30	2
Carduelis	tristis	4	0	0	4.47	2.37	4
Coccothraust	vespertinus	1	6	8	2.16	0.00	0
Sorex	vagrans	4	4	4	6.76	3.77	2
Sorex	pacificus	5	5	5	5.84	0.00	0
Sorex	bendirii	8	8	8	6.25	0.00	0
Sorex	trowbridgii	10	10	10	6.45	0.00	0
Sorex	sonomae	5	5	5	5.15	0.00	0
Neurotrichus	gibbsii	4	6	8	7.08	0.00	0
Scapanus	townsendii	1	1	1	4.48	5.92	8
Scapanus	orarius	8	8	8	6.87	1.51	0
Myotis	lucifugus	4	6	8	4.65	3.23	8
Myotis	yumanensis	2	3	7	3.07	1.69	4
Myotis	evotis	6	6	6	4.65	1.69	2

		For 0-40	For 40-80	For 80 +	Open	Agr	Res
Myotis	thysanodes	3	5	7	2.79	1.23	0
Myotis	volans	1	4	10	2.79	1.23	0
Myotis	californicus	3	5	7	3.79	1.69	1
Lasionycteris	noctivagans	4	3	9	3.45	1.69	3
Eptesicus	fuscus	4	3	9	3.86	3.23	8
Lasiurus	cinereus	1	3	8	4.10	1.01	2
Plecotus	townsendii	2	3	3	2.09	0.77	2
Antrozous	pallidus	0	0	0	1.04	0.77	2
Sylvilagus	bachmani	4	4	4	4.99	0.92	0
Lepus	americanus	10	8	6	5.69	0.00	0
Lepus	californicus	0	0	0	0.74	7.54	0
Aplodontia	rufa	10	10	5	3.85	0.92	0
Tamias	townsendii	10	9	10	6.79	0.00	0
Spermophilus	beecheyi	0	0	0	2.15	4.73	4
Sciurus	griseus	0	6	6	6.92	0.00	2
Tamiasciurus	douglasii	0	9	10	2.91	0.00	0
Glaucomys	sabrinus	0	10	10	4.91	0.00	5
Thomomys	mazama	8	6	0	2.28	1.61	0
Thomomys	bulbivorus	0	0	0	1.68	8.69	7
Castor	canadensis	10	10	10	9.77	6.19	5
Peromyscus	maniculatus	9	9	9	9.02	3.43	3
Neotoma	fuscipes	0	0	0	7.43	0.00	0
Neotoma	cinerea	8	8	8	6.53	0.00	0
Clethrionomy	californicus	3	8	10	4.60	0.00	0
Phenacomys	albipes	10	8	8	3.46	0.00	0
Phenacomys	longicaudus	0	5	10	0.00	0.00	0
Microtus	townsendii	0	0	0	1.30	1.55	0
Microtus	longicaudus	10	0	0	3.43	0.00	0
Microtus	oregoni	10	7	4	4.15	0.00	0
Microtus	canicaudus	0	0	0	1.94	4.70	0
Zapus	trinotatus	4	8	10	5.97	0.00	0
Erethizon	dorsatum	10	10	10	8.34	0.79	0
Canis	latrans	8	7	6	7.37	5.02	5
Vulpes	vulpes	3	2	1	6.19	4.79	3
Urocyon	cinereoargenteu	7	8	9	5.99	0.00	0
Ursus	americanus	8	8	8	7.61	0.70	1
Procyon	lotor	9	9	9	8.70	1.88	10
Martes	americana	7	8	10	4.16	0.00	0
Martes	pennanti	5	8	10	1.92	0.00	0
Mustela	erminea	8	8	8	7.87	1.34	0
Mustela	frenata	8	8	8	7.87	1.34	0
Spilogale	gracilis	8	6	6	6.90	0.00	0
Mephitis	mephitis	4	0	2	5.15	2.56	5
Felis	concolor	10	7	7	8.75	5.10	2
Lynx	rufus	8	8	7	8.10	2.23	2

		For 0-40	For 40-80	For 80+	Open	Agr	Res
Cervus	elaphus	9	6	7	7.09	7.45	1
Odocoileus	hemionus	10	7	7	8.75	6.22	5
Chrysemys	picta	0	0	0	0.37	1.19	0
Clemmys	marmorata	0	0	0	0.42	1.74	0
Elgaria	coerulea	10	5	5	4.21	0.70	3
Elgaria	multicarinata	3	0	0	6.14	1.35	4
Sceloporus	occidentalis	7	2	0	3.08	0.01	3
Eumeces	skiltonianus	2	0	0	2.48	0.01	3
Charina	bottae	7	3	3	5.61	1.12	4
Coluber	constrictor	3	3	3	5.86	3.18	6
Contia	tenuis	4	3	3	7.73	1.35	4
Diadophis	punctatus	3	3	3	5.13	1.35	4
Pituophis	catenifer	3	1	1	4.19	4.17	8
Thamnophis	ordinoides	7	5	3	5.59	3.11	7
Thamnophis	sirtalis	4	3	3	4.07	3.11	7
Crotalus	viridis	0	0	0	4.86	1.35	0

Appendix 3.

Individual per acre indices

		For 0-40	For 40-80	For 80+	Open	Agr	Res
Ambystoma	gracile	0.0451	0.203	0.2256	0.1315	0	0
Ambystoma	macrodactylum	0.0648	0.0648	0.0648	0.1157	0.0823	0.0648
Aneides	ferreus	0.0795	0.1988	0.318	0.0343	0	0
Ensatina	eschscholtzii	0.1014	0.169	0.169	0.116	0.0039	0
Plethodon	dunni	0.0479	0.2393	0.2393	0.0687	0	0
Plethodon	vehiculum	0.0701	0.2336	0.2336	0.0469	0	0
Taricha	granulosa	0.0888	0.1332	0.148	0.1224	0.0274	0
Dicamptodon	tenebrosus	0.0137	0.0685	0.0685	0.028	0	0
Ascaphus	truei	0	0.0751	0.0966	0.0232	0	0
Pseudacris	regilla	0.059	0.0787	0.0787	0.143	0.0669	0.0787
Rana	aurora	0.0118	0.0471	0.0471	0.0378	0.0112	0
Ardea	herodias	0	0.1039	0.1385	0.1975	0.058	0.0346
Butorides	virescens	0.1015	0.1624	0.1624	0.1411	0	0
Branta	canadensis	0	0	0	0.0001	0.0055	0.0054
Aix	sponsa	0	0	0	0.613	0	0
Anas	platyrhynchos	0	0	0	0	0.1931	0
Lophodytes	cucullatus	0	0.0716	0.1432	0.4308	0	0
Cathartes	aura	0.1385	0.0554	0.0969	0.1036	0.0539	0
Pandion	haliaetus	0	0	0.8172	0	0	0.8172
Elanus	leucurus	0	0	0	0.0087	0.0214	0
Haliaeetus	leucocephalus	0	0.0528	0.1584	0.0197	0	0
Circus	cyaneus	0.1006	0	0	0.015	0.1414	0
Accipiter	striatus	0.0742	0.1854	0.1483	0.0996	0.017	0.0185
Accipiter	cooperii	0.057	0.171	0.152	0.1479	0.0134	0.057
Accipiter	gentilis	0	0.0361	0.0452	0	0	0
Buteo	jamaicensis	0.0995	0.0597	0.0796	0.1323	0.0619	0.0398
Aquila	chrysaetos	0.2328	0	0.1164	0.0323	0.0535	0
Falco	sparverius	0.0707	0	0	0.0881	0.1214	0.1885
Dendragapus	obscurus	0.1238	0.1857	0.2063	0.0503	0	0
Bonasa	umbellus	0.1249	0.1458	0.1249	0.151	0	0
Oreortyx	pictus	0.0743	0	0	0.0466	0.0085	0
Charadrius	vociferus	0	0	0	0	0.15	0.7413
Gallinago	gallinago	0	0	0	0	0.1931	0
Brachyramphus	marmoratus	0	0	0.0325	0	0	0
Columba	fasciata	0.1027	0.1797	0.1541	0.1192	0.0001	0
Zenaida	macroura	0.1389	0	0	0.0583	0.1048	0.0868
Tyto	alba	0	0	0.0315	0.0327	0.1589	0.3154
Otus	kennicottii	0.093	0.1488	0.1674	0.1598	0	0.0558
Bubo	virginianus	0.0559	0.1117	0.1397	0.1238	0.0509	0.0419
Glaucidium	gnoma	0.021	0.063	0.07	0.0242	0	0
Athene	cunicularia	0	0	0	0	0.0058	0
Strix	occidentalis	0	0.0301	0.0602	0	0	0
Strix	varia	0	0.1588	0.2858	0.227	0	0
Asio	otus	0.041	0.041	0.0205	0.0536	0	0
Asio	flammeus	0	0	0	0	0.0579	0
Aegolius	acadicus	0.0138	0.062	0.0689	0.0368	0	0
Chordeiles	minor	0.3101	0	0	0.0024	0.0475	0
Chaetura	vauxi	0	0	0.8172	0	0	0.8172

		For 0-40	For 40-80	For 80+	Open	Agr	Res
Calypte	anna	0	0	0	0.1626	0	0.1155
Selasphorus	rufus	0.1581	0.1265	0.1107	0.1197	0	0.0949
Melanerpes	lewis	0	0	0	0.1839	0	0
Melanerpes	formicivorus	0	0	0	0.0765	0.0001	0
Sphyrapicus	ruber	0.0153	0.0535	0.0535	0.0498	0	0.0306
Picoides	pubescens	0.0301	0	0	0.1282	0	0.0602
Picoides	villosus	0.0145	0.0578	0.0723	0.0398	0	0
Colaptes	auratus	0.0762	0.1016	0.1016	0.1292	0.0402	0.2286
Dryocopus	pileatus	0.0158	0.0634	0.0792	0.0261	0	0
Contopus	borealis	0.031	0.0619	0.0774	0.0067	0	0
Contopus	sordidulus	0.032	0.0213	0.0213	0.0845	0	0.0533
Empidonax	traillii	0.1226	0	0	0.0021	0	0
Empidonax	hammondii	0.0454	0.0649	0.0389	0.0028	0	0
Empidonax	difficilis	0.0128	0.0638	0.0638	0.0376	0	0.0064
Tyrannus	verticalis	0	0	0	0.0539	0.1761	0
Eremophila	alpestris	0	0	0	0	0.1931	0
Progne	subis	0.0205	0	0.0818	0	0	0
Tachycineta	bicolor	0.1327	0.0663	0.0995	0.1981	0.0215	0
Tachycineta	thalassina	0.2733	0	0	0.009	0.0422	0.3514
Hirundo	pyrrhonota	0	0	0	0	0	3.319
Hirundo	rustica	0	0	0	0	0.1333	1.0285
Cyanocitta	stelleri	0.1474	0.1659	0.1843	0.0557	0	0
Aphelocoma	californica	0	0	0	0.4194	0.0286	0.556
Corvus	brachyrhynchos	0.0309	0	0	0.0687	0.1391	0.3089
Corvus	corax	0.0157	0.055	0.0785	0.017	0.0068	0
Parus	atricapillus	0.0766	0.0383	0.0383	0.367	0	0.3064
Parus	rufescens	0.1062	0.2124	0.2124	0.0275	0	0.0425
Psaltriparus	minimus	0.2295	0	0	0.2012	0.0121	0.1785
Sitta	canadensis	0.0679	0.2264	0.2264	0.056	0	0.0453
Sitta	carolinensis	0	0	0	0.1786	0	0.0284
Certhia	americana	0.0075	0.0603	0.0754	0.0435	0	0.0075
Thryomanes	bewickii	0.0627	0.009	0	0.0684	0.0021	0.0179
Troglodytes	aedon	0.0611	0.0087	0.0087	0.0583	0.002	0.0611
Troglodytes	troglodytes	0.0394	0.0507	0.0563	0.0219	0	0
Regulus	satrapa	0.021	0.063	0.07	0.0242	0	0
Sialia	mexicana	0.049	0	0	0.0278	0.0248	0.0245
Catharus	ustulatus	0.1372	0.1715	0.1543	0.08	0	0
Turdus	migratorius	0.1095	0.0821	0.0684	0.106	0.0535	0.1095
Ixoreus	naevius	0	0.0752	0.0941	0.0244	0	0
Chamaea	fasciata	0.3429	0	0	0.1044	0	0
Bombycilla	cedrorum	0.1536	0	0	0.2499	0.0248	0.3071
Vireo	solitarius	0.0237	0.0356	0.0237	0.0849	0	0
Vireo	huttoni	0.008	0.064	0.048	0.0544	0	0
Vireo	gilvus	0.0868	0	0	0.4521	0	0.1737
Vermivora	celata	0.2198	0	0	0.2812	0	0.0314
Dendroica	petechia	0	0	0	0.1839	0	0
Dendroica	coronata	0	0.2597	0.3029	0.0748	0	0
Dendroica	nigrescens	0.0785	0.1177	0.0785	0.2859	0	0
Dendroica	occidentalis	0.0145	0.0726	0.0726	0.0188	0	0

		For 0-40	For 40-80	For 80+	Open	Agr	Res
Oporornis	tolmiei	0.0997	0	0	0.0361	0	0
Geothlypis	trichas	0	0	0	0.1626	0.1419	0
Wilsonia	pusilla	0.1891	0.1681	0	0.0949	0	0
Icteria	virens	0	0	0	0.1839	0	0
Piranga	ludoviciana	0.0529	0.2116	0.1851	0.1309	0	0
Pheucticus	melanocephalus	0.0321	0.1606	0.1606	0.2476	0	0
Passerina	amoena	0	0	0	0.1355	0.0152	0
Pipilo	maculatus	0.0513	0.0086	0	0.0628	0.0079	0.0428
Spizella	passerina	0.0307	0	0	0.074	0.0176	0.046
Poecetes	gramineus	0	0	0	0.0147	0.0533	0
Passerculus	sandwichensis	0	0	0	0.0132	0.189	0
Ammodramus	savannarum	0	0	0	0.0031	0.0048	0
Melospiza	melodia	0.1581	0.0452	0.0226	0.1148	0.0511	0.1355
Zonotrichia	leucophrys	0.1857	0	0	0.1058	0.0649	0.1393
Junco	hyemalis	0.1194	0.1592	0.0796	0.0861	0.0229	0.0398
Agelaius	phoeniceus	0	0	0	0.0226	0.186	0
Sturnella	neglecta	0	0	0	0.0114	0.0544	0
Euphagus	cyanocephalus	0	0	0	0.0378	0.1611	0.3453
Molothrus	ater	0.1061	0.0637	0.0424	0.1216	0.0644	0.0849
Icterus	bullockii	0.044	0	0	0.1023	0	0.0881
Carpodacus	purpureus	0.0324	0.054	0.0432	0.0352	0	0
Carpodacus	mexicanus	0	0	0	0.2593	0.0789	0.5599
Loxia	curvirostra	0.0084	0.0756	0.0756	0.0218	0	0
Carduelis	pinus	0.1221	0.1953	0.2198	0.0316	0	0
Carduelis	psaltria	0	0	0	0.0899	0.0272	0.0419
Carduelis	tristis	0.0394	0	0	0.044	0.0234	0.0394
Coccothraustes	vespertinus	0.0368	0.221	0.2946	0.0795	0	0
Sorex	vagrans	0.0223	0.0223	0.0223	0.0377	0.0211	0.0112
Sorex	pacificus	0.0165	0.0165	0.0165	0.0193	0	0
Sorex	bendirii	0.0433	0.0433	0.0433	0.0339	0	0
Sorex	trowbridgii	0.0448	0.0448	0.0448	0.0289	0	0
Sorex	sonomae	0.1365	0.1365	0.1365	0.1405	0	0
Neurotrichus	gibbsii	0.0283	0.0424	0.0565	0.0501	0	0
Scapanus	townsendii	0.0065	0.0065	0.0065	0.0292	0.0386	0.0522
Scapanus	orarius	0.1246	0.1246	0.1246	0.107	0.0235	0
Myotis	lucifugus	0.0208	0.0312	0.0417	0.0242	0.0168	0.0417
Myotis	yumanensis	0.0075	0.0113	0.0264	0.0116	0.0064	0.0151
Myotis	evotis	0.0148	0.0148	0.0148	0.0114	0.0042	0.0049
Myotis	thysanodes	0.0104	0.0173	0.0242	0.0097	0.0043	0
Myotis	volans	0.0039	0.0157	0.0393	0.011	0.0048	0
Myotis	californicus	0.0222	0.0371	0.0519	0.0281	0.0125	0.0074
Lasionycteris	noctivagans	0.0299	0.0224	0.0672	0.0257	0.0126	0.0224
Eptesicus	fuscus	0.0238	0.0179	0.0536	0.023	0.0193	0.0477
Lasiurus	cinereus	0.0103	0.0308	0.0822	0.0421	0.0103	0.0205
Plecotus	townsendii	0.0266	0.04	0.04	0.0278	0.0103	0.0266
Antrozous	pallidus	0	0	0	0.0207	0.0153	0.0397
Sylvilagus	bachmani	0.1127	0.1127	0.1127	0.1407	0.0259	0
Lepus	americanus	0.0522	0.0418	0.0313	0.0297	0	0
Lepus	californicus	0	0	0	0.0055	0.0562	0

		For 0-40	For 40-80	For 80 +	Open	Agr	Res
Aplodontia	rufa	0.0477	0.0477	0.0238	0.0184	0.0044	0
Tamias	townsendii	0.046	0.0414	0.046	0.0312	0	0
Spermophilus	beecheyi	0	0	0	0.0735	0.162	0.1371
Sciurus	griseus	0	0.0575	0.0575	0.0664	0	0.0192
Tamiasciurus	douglasii	0	0.2593	0.2881	0.0837	0	0
Glaucomys	sabrinus	0	0.0718	0.0718	0.0352	0	0.0359
Thomomys	mazama	0.1768	0.1326	0	0.0505	0.0355	0
Thomomys	bulbivorus	0	0	0	0.0101	0.0523	0.0421
Castor	canadensis	0.0944	0.0944	0.0944	0.0922	0.0584	0.0472
Peromyscus	maniculatus	0.1069	0.1069	0.1069	0.1072	0.0407	0.0356
Neotoma	fuscipes	0	0	0	0.1839	0	0
Neotoma	cinerea	0.1433	0.1433	0.1433	0.1169	0	0
Clethrionomys	californicus	0.0212	0.0566	0.0707	0.0325	0	0
Phenacomys	albipes	0.0225	0.018	0.018	0.0078	0	0
Phenacomys	longicaudus	0	0.0723	0.1446	0	0	0
Microtus	townsendii	0	0	0	0.0383	0.0459	0
Microtus	longicaudus	0.3358	0	0	0.115	0	0
Microtus	oregoni	0.0591	0.0413	0.0236	0.0245	0	0
Microtus	canicaudus	0	0	0	0.0704	0.1709	0
Zapus	trinotatus	0.0255	0.051	0.0637	0.038	0	0
Erethizon	dorsatum	0.1348	0.1348	0.1348	0.1125	0.0107	0
Canis	latrans	0.0993	0.0869	0.0745	0.0915	0.0623	0.0621
Vulpes	vulpes	0.0185	0.0123	0.0062	0.0382	0.0296	0.0185
Urocyon	cinereoargenteus	0.0393	0.0449	0.0505	0.0336	0	0
Ursus	americanus	0.039	0.039	0.039	0.0371	0.0034	0.0049
Procyon	lotor	0.1157	0.1157	0.1157	0.1119	0.0242	0.1286
Martes	americana	0.017	0.0195	0.0243	0.0101	0	0
Martes	pennanti	0.0035	0.0056	0.007	0.0013	0	0
Mustela	erminea	0.1232	0.1232	0.1232	0.1211	0.0206	0
Mustela	frenata	0.1232	0.1232	0.1232	0.1211	0.0206	0
Spilogale	gracilis	0.048	0.036	0.036	0.0414	0	0
Mephitis	mephitis	0.1154	0	0.0577	0.1486	0.0737	0.1442
Felis	concolor	0.0341	0.0238	0.0238	0.0298	0.0174	0.0068
Lynx	rufus	0.0345	0.0345	0.0302	0.0349	0.0096	0.0086
Cervus	elaphus	0.0973	0.0649	0.0757	0.0767	0.0805	0.0108
Odocoileus	hemionus	0.1055	0.0738	0.0738	0.0923	0.0656	0.0527
Chrysemys	picta	0	0	0	0.0016	0.0053	0
Clemmys	marmorata	0	0	0	0.0013	0.0054	0
Elgaria	coerulea	0.1933	0.0966	0.0966	0.0813	0.0136	0.058
Elgaria	multicarinata	0.1177	0	0	0.2411	0.053	0.157
Sceloporus	occidentalis	0.2543	0.0727	0	0.112	0.0003	0.109
Eumeces	skiltonianus	0.2032	0	0	0.2522	0.001	0.3048
Charina	bottae	0.0491	0.021	0.021	0.0394	0.0078	0.0281
Coluber	constrictor	0.0201	0.0201	0.0201	0.0392	0.0213	0.0402
Contia	tenuis	0.0124	0.0093	0.0093	0.0241	0.0042	0.0124
Diadophis	punctatus	0.0269	0.0269	0.0269	0.0459	0.0121	0.0358
Pituophis	catenifer	0.0726	0.0242	0.0242	0.1014	0.1009	0.1935
Thamnophis	ordinoides	0.1195	0.0854	0.0512	0.0955	0.0531	0.1195
Thamnophis	sirtalis	0.0905	0.0679	0.0679	0.092	0.0703	0.1584
Crotalus	viridis	0	0	0	0.0977	0.0272	0

Appendix 4.

Current and high conservation land allocations

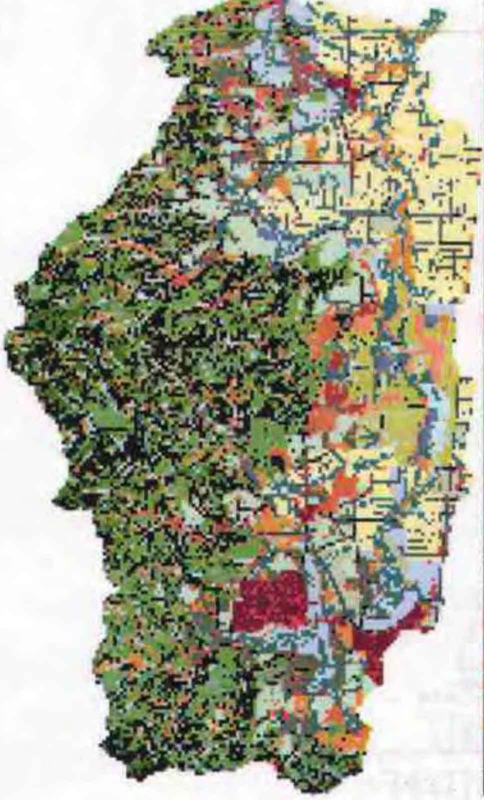
Original acres 1990

	For 0-40	For 40-80	For 80+	Open	Agr	Res
s1ss1	1085.7	1067.5	98.7	1334.8	10638.7	642.7
s1ss2	2057.1	1987.8	410.3	1264.3	1742.7	224.6
s2ss1	673.0	685.9	233.7	1214.5	10787.4	283.3
s2ss2	3628.1	3137.8	1667.1	1663.5	585.1	94.1
s3ss1	672.1	766.8	143.0	477.7	1112.0	110.1
s3ss2	3981.1	3880.3	2059.1	2202.4	1024.1	151.7

Where:

S1ss1 = good soils, < 10% slope
S1ss2 = good soils, > 10% slope
S2ss1 = moderate soils, < 10% slope
S2ss2 = moderate soils, > 10% slope
S3ss1 = poor soils, < 10% slope
S3ss2 = poor soils, > 10% slope

2025 ISE High Conservation Land Allocations:



Category	Acres	Percentage Of	
Agriculture		Category	Total
Grass Seed/Grain	7,141	40.9%	8.8%
Hybrid Poplar for Pulp	420	2.4%	0.5%
Hybrid Poplar for Veneer	2,159	12.4%	2.7%
Orchards	32	0.2%	0.0%
Pasture	2,316	13.3%	2.9%
Row Crops	906	5.2%	1.1%
Vineyards	103	0.6%	0.1%
Xmas Tree	4,390	25.1%	5.4%
Agriculture Total	17,466	100.0%	21.6%
Built			
Commercial	2	0.0%	0.0%
Railroad	179	2.5%	0.2%
Roads	4,929	69.7%	6.1%
Trail	837	11.8%	1.0%
Within 2 acres of structures	1,127	15.9%	1.4%
Built Total	7,074	100.0%	8.8%
Forestry			
0-40 yr Doug fir	1,944	6.8%	2.4%
41-80 yr Doug fir	11,273	39.2%	14.0%
81-120 yr Doug fir	4,904	17.1%	6.1%
120+ yr Doug fir	10,605	36.9%	13.1%
Forestry Total	28,726	100.0%	35.6%
Hydro			
Headwater steams	2,271	56.3%	2.8%
Open standing water	559	13.9%	0.7%
Streams (>1st order)	1,203	29.8%	1.5%
Hydro Total	4,033	100.0%	5.0%
Non Ag-Veg			
Hedgerows/Windbreaks	7,628	32.5%	9.4%
Mixed conifer	3,092	13.2%	3.8%
Non-treed wetlands - marsh	674	2.9%	0.8%
Oak & other hardwood	2,741	11.7%	3.4%
Oak Savanna	1,042	4.4%	1.3%
Prairie	548	2.3%	0.7%
Shrub/brush	1,099	4.7%	1.4%
Wet riparian with trees	6,657	28.4%	8.2%
Non Ag-Veg Total	23,482	100.0%	29.1%
Grand Total	80,782		100.0%

Courtesy: Hulse et al. 1997

Appendix 5.

Demand curve coefficients

	Original		Adjusted for High Development	
s1ss1	alpha	beta	alpha	beta
res	7227	-7.0589	9573	-7.0589
open	3150.5	-0.7162	3283.2	-0.7162
ag	1914.7	-0.0912	1917.6	-0.0912
for	1686.4	-0.0731	1686.4	-0.0731
s1ss2				
res	4934	-15.448	8122.2	-15.448
ag	1479.5	-0.0673	1485.4	-0.0673
open	1420.3	-0.0372	1421.9	-0.0372
for	1371.8	-0.0222	1371.8	-0.0222
s2ss1				
res	4728.4	-11.717	7047.9	-11.717
open	1469.5	-0.2141	1426.4	-0.2141
ag	1207.6	-0.0393	1207.6	-0.0393
for	853.17	-0.0104	588.6	-0.0104
s2ss2				
res	3649.9	-11.611	4633.3	-11.611
ag	2675.1	-1.2516	2726.2	-1.2516
open	2387.5	-0.8281	2408.9	-0.8281
for	474.72	-0.0116	474.2	-0.0116
s3ss1				
res	5806	-32.553	11524.1	-32.553
ag	2295.9	-0.6726	2144.9	-0.6726
open	1844.8	-0.4188	1779.4	-0.4188
for	1470.8	-0.253	1470.8	-0.253
s3ss2				
res	3721	-11.471	6896.6	-11.471
ag	2059.2	-0.5165	2101.8	-0.5165
open	2009.5	-0.4741	2044.2	-0.4741
for	444.51	-0.0109	444.5	-0.0109

Appendix 6.

GAMS MINOS5 code

```
$TITLE MUDDY CREEK


$OFFUPPER
$OFFSYMXREF

SET HAB    HABITAT
/ ncon, mcon, ocon, open, agr, res/;

set hab2   new habs with seven for choices
/ f40, f45, f50, f60, f80, f120, park, open1, agr1, res1/;

SET ELSO SITE PRODUCTIVITY  SOIL SLOPE
/S1SS1, S1SS2, S2SS1, S2SS2, S3SS1, S3SS2
/;


SET S  SPECIES
/ a1,
    a2,
    a3,
    a4,
    . . .
   a196
 /;

TABLE  AC(ELSO,HAB2)    ACRES IN EACH HABITAT CLASS
$INCLUDE "k:\shunkn\GAMS\ACRES.TXT";

table ac1(elso,hab)   acres original in each ncon mcon etc
$include "k:\shunkn\gams\acres1.txt";

table qmid1(elso,hab2)  original acres mid points
$include "k:\shunkn\gams\mid1.txt";

TABLE alpha(ELSO,HAB2)   land value alphas FOR EACH HABITAT CLASS
$INCLUDE "k:\shunkn\GAMS\alpha.TXT";

TABLE beta(ELSO,HAB2)   land value betas ag open res equal 0
$INCLUDE "k:\shunkn\GAMS\beta.TXT";

TABLE adjust(ELSO,HAB2)   percent of lv sev adjustments  ag open res equal 1
$INCLUDE "k:\shunkn\GAMS\adjust.TXT";

TABLE SPAC(S,HAB)   SPECIES PER ACRE
$INCLUDE "k:\shunkn\GAMS\SPAC11.TXT";

PARAMETERS TOT(ELSO)   TOTAL AREA

/  S1SS1    14868.15
   S1SS2     7686.83
   S2SS1    13877.83
   S2SS2    10775.66
   S3SS1     3281.65
   S3SS2    13298.72
 /;
```

```
PARAMETERS WT(S)   SPECIE WEIGHTS

/   a1       1.429
    a2       1.429
    a3        1.25
. . .

   a196           2/ ;


SCALAR BIOPRICE  / 1000 /;
SCALAR MPRICE    / 1 /;
SCALAR ALPH     / 3.2 /;
SCALAR BET      / 1.9 /;
SCALAR THETA     / 1000 /;

VARIABLES
ADAC2(ELSO,HAB2)    ADJUSTED ACRES
MBVAL;
POSITIVE VARIABLE ADAC2 ;

EQUATIONS
EQ1(ELSO)  CANT MOVE TO NEW ELSO

OBJ;

EQ1(ELSO)..
SUM(HAB2, ADAC2(ELSO,HAB2)) =l= TOT(ELSO);


OBJ..
MBVAL =E= BIOPRICE * SUM(S,WT(S)/(1+EXP(-ALPH-BET *
LOG(.01 + (1/THETA) *
(
(spac(s,"res")* sum(elso,adac2(elso,"res1")))+

(spac(s,"open") * sum(elso, adac2(elso,"open1"))) +

(spac(s,"agr") * sum(elso, adac2(elso,"agr1"))) +

(spac(s,"ncon") * sum(elso,((adac2(elso,"f40") + .888*adac2(elso,"f45") + .8*adac2(elso,"f50")+
.6666*adac2(elso,"f60") + .5 * adac2(elso,"f80") + .3333 * adac2(elso,"f120")))) +

(spac(s,"mcon") * sum(elso,((.5*adac2(elso,"f80") + .111* adac2(elso,"f45") +
.2 * adac2(elso,"f50") + .333* adac2(elso,"f60") + .333 * adac2(elso,"f120")))) +

(spac(s,"ocon") * sum(elso, ((.333 * adac2(elso,"f120") + adac2(elso,"park"))))
)))))))


+ MPRICE *

(
(sum(elso, (adac2(elso,"res1")/2 * beta(elso,"res1") + alpha(elso,"res1") * adjust(elso,"res1")) *
```

```
adac2(elso,"res1"))) +

(adac2("s1ss1","open1") * ((adac2("s1ss1","res1") + adac2("s1ss1","open1")/2) *
 beta("s1ss1","open1") + alpha("s1ss1","open1")*adjust("s1ss1","open1"))) +

(adac2("s1ss2","agr1") * ((adac2("s1ss2","res1") + adac2("s1ss2","agr1")/2) *
 beta("s1ss2","agr1") + alpha("s1ss2","agr1")*adjust("s1ss2","agr1"))) +

(adac2("s2ss1","open1") * ((adac2("s2ss1","res1") + adac2("s2ss1","open1")/2) *
beta("s2ss1","open1") + alpha("s2ss1","open1") * adjust("s2ss1","open1"))) +

(adac2("s2ss2","agr1") * ((adac2("s2ss2","res1") + adac2("s2ss2","agr1")/2) *
beta("s2ss2","agr1") + alpha("s2ss2","agr1") * adjust("s2ss2","agr1"))) +

(adac2("s3ss1","agr1") * ((adac2("s3ss1","res1") + adac2("s3ss1","agr1")/2) *
beta("s3ss1","agr1") + alpha("s3ss1","agr1") * adjust("s3ss1","agr1")))  +

(adac2("s3ss2","agr1") * ((adac2("s3ss2","res1") + adac2("s3ss2","agr1")/2) *
beta("s3ss2","agr1") + alpha("s3ss2","agr1") * adjust("s3ss2","agr1"))) +

(adac2("s1ss1","agr1") * ((adac2("s1ss1","res1") + adac2("s1ss1","open1") +
 adac2("s1ss1","agr1")/2) * beta("s1ss1","agr1") + alpha("s1ss1","agr1") *
adjust("s1ss1","agr1"))) +


(adac2("s1ss2","open1") * ((adac2("s1ss2","res1") + adac2("s1ss2","agr1") +
 adac2("s1ss2","open1")/2) * beta("s1ss2","open1") + alpha("s1ss2","open1") *
adjust("s1ss2","open1")))  +

(adac2("s2ss1","agr1") * ((adac2("s2ss1","res1") + adac2("s2ss1","open1") +
adac2("s2ss1","agr1")/2) * beta("s2ss1","agr1") + alpha("s2ss1","agr1") *
adjust("s2ss1","agr1")))  +

(adac2("s2ss2","open1") * ((adac2("s2ss2","res1") + adac2("s2ss2","agr1") +
adac2("s2ss2","open1")/2) * beta("s2ss2","open1") + alpha("s2ss2","open1") *
adjust("s2ss2","open1")))  +

(adac2("s3ss1","open1") * ((adac2("s3ss1","res1") + adac2("s3ss1","agr1") +
 adac2("s3ss1","open1")/2) * beta("s3ss1","open1") + alpha("s3ss1","open1") *
adjust("s3ss1","open1")))  +

(adac2("s3ss2","open1") * ((adac2("s3ss2","res1") + adac2("s3ss2","agr1") +
adac2("s3ss2","open1")/2) * beta("s3ss2","open1") + alpha("s3ss2","open1") *
adjust("s3ss1","open1")))  +


sum(elso,(adac2(elso,"f40") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f40") + alpha(elso,"f40") * adjust(elso,"f40")))))  +


sum(elso,(adac2(elso,"f45") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f45") + alpha(elso,"f45") * adjust(elso,"f45")))))  +
```

```
sum(elso,(adac2(elso,"f50") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f50") + alpha(elso,"f50") * adjust(elso,"f50"))))) +

sum(elso,(adac2(elso,"f60") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f60") + alpha(elso,"f60") * adjust(elso,"f60"))))) +

sum(elso,(adac2(elso,"f80") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f80") + alpha(elso,"f80") * adjust(elso,"f80"))))) +

sum(elso,(adac2(elso,"f120") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"f120") + alpha(elso,"f120") * adjust(elso,"f120"))))) +

sum(elso,(adac2(elso,"park") * (((adac2(elso,"res1") + adac2(elso,"open1") + adac2(elso,"agr1") +
(adac2(elso,"f40")+
adac2(elso,"f45")+ adac2(elso,"f50") + adac2(elso,"f60") + adac2(elso,"f80") + adac2(elso,"f120") +
adac2(elso,"park"))/2) * beta(elso,"park") + alpha(elso,"park") * adjust(elso,"park")))))
)
- sum(elso, sum(hab2, (adac2(elso, hab2) * adjust(elso, hab2))));




MODEL MUDDY / ALL /;
SOLVE MUDDY USING NLP MAXIMIZING MBVAL;
PARAMETERS

olv   original land value
NLV   NEW LAND VALUE
OBIO  ORIGINAL BIO VALUE
NBIO  NEW BIO VALUE
EXPD  EXPECTED DIVERSITY
AB(S) SPECIES POPULATION INDEX
NAB(S) NEW SPECIES POPULATION INDEX
AREA  TOTAL ACRES;

olv = (sum(elso, (ac(elso,"res1")/2 * beta(elso,"res1") + alpha(elso,"res1") * adjust(elso,"res1")) *
ac(elso,"res1"))) +

(ac("s1ss1","open1") * ((ac("s1ss1","res1") + ac("s1ss1","open1")/2) *
 beta("s1ss1","open1") + alpha("s1ss1","open1")*adjust("s1ss1","open1"))) +

(ac("s1ss2","agr1") * ((ac("s1ss2","res1") + ac("s1ss2","agr1")/2) *
 beta("s1ss2","agr1") + alpha("s1ss2","agr1")*adjust("s1ss2","agr1"))) +

(ac("s2ss1","open1") * ((ac("s2ss1","res1") + ac("s2ss1","open1")/2) *
```

```
beta("s2ss1","open1") + alpha("s2ss1","open1") * adjust("s2ss1","open1"))) +

(ac("s2ss2","agr1") * ((ac("s2ss2","res1") + ac("s2ss2","agr1")/2) *
beta("s2ss2","agr1") + alpha("s2ss2","agr1") * adjust("s2ss2","agr1"))) +

(ac("s3ss1","agr1") * ((ac("s3ss1","res1") + ac("s3ss1","agr1")/2) *
beta("s3ss1","agr1") + alpha("s3ss1","agr1") * adjust("s3ss1","agr1"))) +

(ac("s3ss2","agr1") * ((ac("s3ss2","res1") + ac("s3ss2","agr1")/2) *
beta("s3ss2","agr1") + alpha("s3ss2","agr1") * adjust("s3ss2","agr1"))) +

(ac("s1ss1","agr1") * ((ac("s1ss1","res1") + ac("s1ss1","open1") +
ac("s1ss1","agr1")/2) * beta("s1ss1","agr1") + alpha("s1ss1","agr1") *
adjust("s1ss1","agr1"))) +


(ac("s1ss2","open1") * ((ac("s1ss2","res1") + ac("s1ss2","agr1") +
ac("s1ss2","open1")/2) * beta("s1ss2","open1") + alpha("s1ss2","open1") *
adjust("s1ss2","open1"))) +

(ac("s2ss1","agr1") * ((ac("s2ss1","res1") + ac("s2ss1","open1") +
ac("s2ss1","agr1")/2) * beta("s2ss1","agr1") + alpha("s2ss1","agr1") *
adjust("s2ss1","agr1"))) +

(ac("s2ss2","open1") * ((ac("s2ss2","res1") + ac("s2ss2","agr1") +
ac("s2ss2","open1")/2) * beta("s2ss2","open1") + alpha("s2ss2","open1") *
adjust("s2ss2","open1"))) +

(ac("s3ss1","open1") * ((ac("s3ss1","res1") + ac("s3ss1","agr1") +
ac("s3ss1","open1")/2) * beta("s3ss1","open1") + alpha("s3ss1","open1") *
adjust("s3ss1","open1"))) +

(ac("s3ss2","open1") * ((ac("s3ss2","res1") + ac("s3ss2","agr1") +
ac("s3ss2","open1")/2) * beta("s3ss2","open1") + alpha("s3ss2","open1") *
adjust("s3ss1","open1"))) +


sum(elso,(ac(elso,"f40") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"f40") + alpha(elso,"f40") * adjust(elso,"f40"))))) +


sum(elso,(ac(elso,"f45") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"f45") + alpha(elso,"f45") * adjust(elso,"f45"))))) +

sum(elso,(ac(elso,"f50") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"f50") + alpha(elso,"f50") * adjust(elso,"f50"))))) +

sum(elso,(ac(elso,"f60") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
```

```
ac(elso,"park"))/2) * beta(elso,"f60") + alpha(elso,"f60") * adjust(elso,"f60"))))) +

sum(elso,(ac(elso,"f80") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"f80") + alpha(elso,"f80") * adjust(elso,"f80"))))) +

sum(elso,(ac(elso,"f120") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"f120") + alpha(elso,"f120") * adjust(elso,"f120"))))) +

sum(elso,(ac(elso,"park") * (((ac(elso,"res1") + ac(elso,"open1") + ac(elso,"agr1") +
(ac(elso,"f40")+
ac(elso,"f45")+ ac(elso,"f50") + ac(elso,"f60") + ac(elso,"f80") + ac(elso,"f120") +
ac(elso,"park"))/2) * beta(elso,"park") + alpha(elso,"park") * adjust(elso,"park")))));

NLV = (sum(elso, (adac2.l(elso,"res1")/2 * beta(elso,"res1") + alpha(elso,"res1") * adjust(elso,"res1"))
*
adac2.l(elso,"res1"))) +

(adac2.l("s1ss1","open1") * ((adac2.l("s1ss1","res1") + adac2.l("s1ss1","open1")/2) *
beta("s1ss1","open1") + alpha("s1ss1","open1")*adjust("s1ss1","open1"))) +

(adac2.l("s1ss2","agr1") * ((adac2.l("s1ss2","res1") + adac2.l("s1ss2","agr1")/2) *
beta("s1ss2","agr1") + alpha("s1ss2","agr1")*adjust("s1ss2","agr1"))) +

(adac2.l("s2ss1","open1") * ((adac2.l("s2ss1","res1") + adac2.l("s2ss1","open1")/2) *
beta("s2ss1","open1") + alpha("s2ss1","open1") * adjust("s2ss1","open1"))) +

(adac2.l("s2ss2","agr1") * ((adac2.l("s2ss2","res1") + adac2.l("s2ss2","agr1")/2) *
beta("s2ss2","agr1") + alpha("s2ss2","agr1") * adjust("s2ss2","agr1"))) +

(adac2.l("s3ss1","agr1") * ((adac2.l("s3ss1","res1") + adac2.l("s3ss1","agr1")/2) *
beta("s3ss1","agr1") + alpha("s3ss1","agr1") * adjust("s3ss1","agr1"))) +

(adac2.l("s3ss2","agr1") * ((adac2.l("s3ss2","res1") + adac2.l("s3ss2","agr1")/2) *
beta("s3ss2","agr1") + alpha("s3ss2","agr1") * adjust("s3ss2","agr1"))) +

(adac2.l("s1ss1","agr1") * ((adac2.l("s1ss1","res1") + adac2.l("s1ss1","open1") +
adac2.l("s1ss1","agr1")/2) * beta("s1ss1","agr1") + alpha("s1ss1","agr1") *
adjust("s1ss1","agr1"))) +

(adac2.l("s1ss2","open1") * ((adac2.l("s1ss2","res1") + adac2.l("s1ss2","agr1") +
adac2.l("s1ss2","open1")/2) * beta("s1ss2","open1") + alpha("s1ss2","open1") *
adjust("s1ss2","open1"))) +

(adac2.l("s2ss1","agr1") * ((adac2.l("s2ss1","res1") + adac2.l("s2ss1","open1") +
adac2.l("s2ss1","agr1")/2) * beta("s2ss1","agr1") + alpha("s2ss1","agr1") *
adjust("s2ss1","agr1"))) +

(adac2.l("s2ss2","open1") * ((adac2.l("s2ss2","res1") + adac2.l("s2ss2","agr1") +
adac2.l("s2ss2","open1")/2) * beta("s2ss2","open1") + alpha("s2ss2","open1") *
adjust("s2ss2","open1"))) +
```

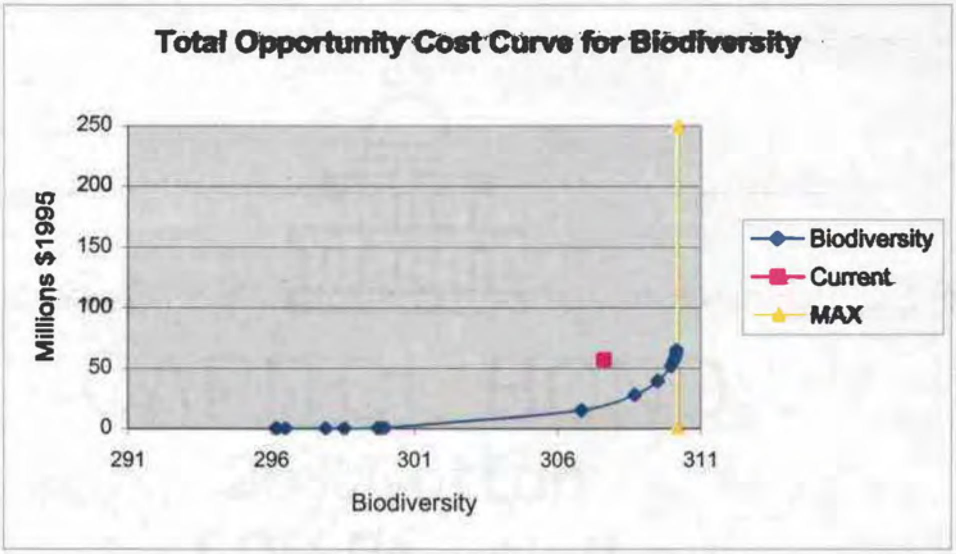
```
(adac2.l("s3ss1","open1") * ((adac2.l("s3ss1","res1") + adac2.l("s3ss1","agr1") +
 adac2.l("s3ss1","open1")/2) * beta("s3ss1","open1") + alpha("s3ss1","open1") *
adjust("s3ss1","open1"))) +

(adac2.l("s3ss2","open1") * ((adac2.l("s3ss2","res1") + adac2.l("s3ss2","agr1") +
adac2.l("s3ss2","open1")/2) * beta("s3ss2","open1") + alpha("s3ss2","open1") *
adjust("s3ss1","open1"))) +


sum(elso,(adac2.l(elso,"f40") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1") +
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f40") + alpha(elso,"f40") * adjust(elso,"f40"))))) +


sum(elso,(adac2.l(elso,"f45") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1") +
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f45") + alpha(elso,"f45") * adjust(elso,"f45"))))) +

sum(elso,(adac2.l(elso,"f50") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1") +
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f50") + alpha(elso,"f50") * adjust(elso,"f50"))))) +

sum(elso,(adac2.l(elso,"f60") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1") +
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f60") + alpha(elso,"f60") * adjust(elso,"f60"))))) +

sum(elso,(adac2.l(elso,"f80") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1") +
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f80") + alpha(elso,"f80") * adjust(elso,"f80"))))) +

sum(elso,(adac2.l(elso,"f120") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1")
+
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"f120") + alpha(elso,"f120") * adjust(elso,"f120"))))) +

sum(elso,(adac2.l(elso,"park") * (((adac2.l(elso,"res1") + adac2.l(elso,"open1") + adac2.l(elso,"agr1")
+
(adac2.l(elso,"f40")+
adac2.l(elso,"f45")+ adac2.l(elso,"f50") + adac2.l(elso,"f60") + adac2.l(elso,"f80") +
adac2.l(elso,"f120") +
adac2.l(elso,"park"))/2) * beta(elso,"park") + alpha(elso,"park") * adjust(elso,"park")))));

OBIO = SUM(S,WT(S)/(1+EXP(-ALPH -BET *
LOG(.01 + (1/THETA) * SUM(ELSO, SUM(HAB, SPAC(S,HAB)*
```

```
AC1(ELSO,HAB)))))));

EXPD = SUM(S,WT(S)/(1+EXP(-ALPH-BET *
LOG(.01 + (1/THETA) *
(
(spac(s,"res")* sum(elso,adac2.l(elso,"res1")))+

(spac(s,"open") * sum(elso, adac2.l(elso,"open1"))) +

(spac(s,"agr") * sum(elso, adac2.l(elso,"agr1"))) +

(spac(s,"ncon") * sum(elso,((adac2.l(elso,"f40") + .888*adac2.l(elso,"f45") + .8*adac2.l(elso,"f50")+
.6666*adac2.l(elso,"f60") + .5 * adac2.l(elso,"f80") + .3333 * adac2.l(elso,"f120")))) +

(spac(s,"mcon") * sum(elso,((.5*adac2.l(elso,"f80") + .111* adac2.l(elso,"f45") +
.2 * adac2.l(elso,"f50") + .333* adac2.l(elso,"f60") + .333 * adac2.l(elso,"f120")))) +

(spac(s,"ocon") * sum(elso, ((.333 * adac2.l(elso,"f120") + adac2.l(elso,"park"))))
 )))))))

;

NBIO = EXPD * BIOPRICE;

AB(S) = SUM(HAB,SPAC(S,HAB) * SUM(ELSO,AC1(ELSO,HAB)));

NAB(S) = (spac(s,"res")* sum(elso,adac2.l(elso,"res1")))+

(spac(s,"open") * sum(elso, adac2.l(elso,"open1"))) +

(spac(s,"agr") * sum(elso, adac2.l(elso,"agr1"))) +

(spac(s,"ncon") * sum(elso,((adac2.l(elso,"f40") + .888*adac2.l(elso,"f45") + .8*adac2.l(elso,"f50")+
.6666*adac2.l(elso,"f60") + .5 * adac2.l(elso,"f80") + .3333 * adac2.l(elso,"f120"))))) +

(spac(s,"mcon") * sum(elso,((.5*adac2.l(elso,"f80") + .111* adac2.l(elso,"f45") +
.2 * adac2.l(elso,"f50") + .333* adac2.l(elso,"f60") + .333 * adac2.l(elso,"f120"))))) +

(spac(s,"ocon") * sum(elso, ((.333 * adac2.l(elso,"f120") + adac2.l(elso,"park")))));


FILE RES / k:\shunkn\gams\output\1000.out /

PUT RES;
PUT /"MPRICE = " MPRICE//;
PUT /"BIODIVERSITY PRICE =" BIOPRICE//;
PUT /"ORIGINAL MARKET VALUE =" OLV//;
PUT /"NEW MARKET VALUE =" NLV//;
PUT /"ORIGINAL BIODIVERSITY VALUE =" OBIO//;
PUT /"NEW BIODIVERSITY VALUE =" NBIO//;
PUT /"EXPECTED BIODIVERSITY INDEX =" EXPD//;

PUT
"SPECIES    ORIG ABUNDANCE    NEW ABUNDANCE"//;
LOOP (S, PUT S.TL:18, AB(S):18:1 NAB(S):18:3/;
);
```

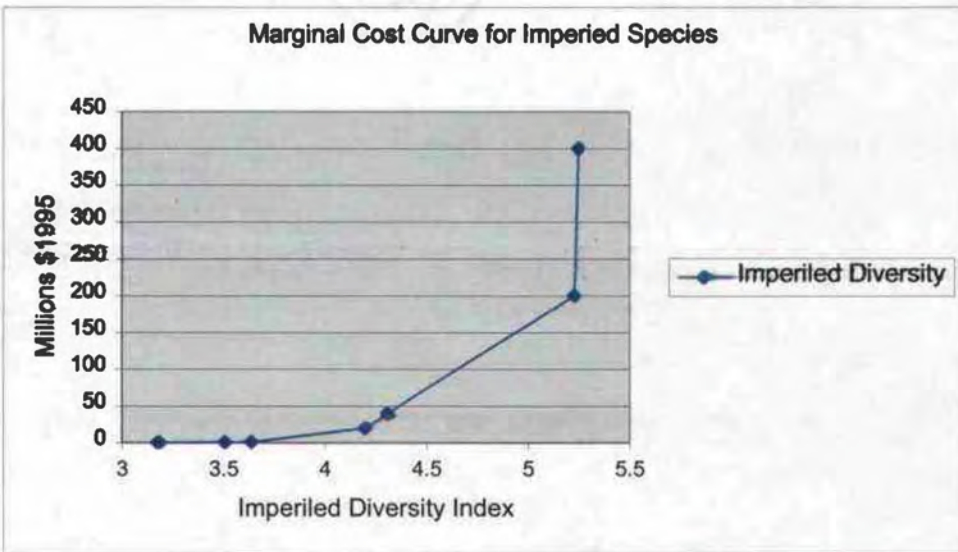
```
PUT /"ADJUSTED AREAS"//;
PUT "            f40         f45          f50"//;
LOOP (ELSO, PUT ELSO.TL:9:1, ADAC2.L(ELSO,'f40'):15:1,
ADAC2.L(ELSO,'f45'):15:1,ADAC2.L(ELSO,'f50'):15:1/;
);

PUT /"ADJUSTED AREAS CONTINUED"//;
PUT "            f60         f80          f120"//;
LOOP (ELSO, PUT ELSO.TL:9:1,ADAC2.L(ELSO,'f60'):15:1,
ADAC2.L(ELSO,'f80'):15:1,ADAC2.L(ELSO,'f120'):15:1/;
);

PUT /"ADJUSTED AREAS CONTINUED"//;
PUT "            park        open         agr"//;
LOOP (ELSO, PUT ELSO.TL:9:1,ADAC2.L(ELSO,'park'):15:1,
ADAC2.L(ELSO,'open1'):15:1,ADAC2.L(ELSO,'agr1'):15:1/;
);

PUT /"ADJUSTED AREAS CONTINUED"//;
PUT "            res "//;
LOOP (ELSO, PUT ELSO.TL:9:1,ADAC2.L(ELSO,'res1'):15:1/;
);
```

Appendix 7.

Total opportunity cost curve for biodiversity
Marginal cost curve, imperiled species biodiversity.



Total Opportunity Cost Curve for Biodiversity
Millions $1995
250
200
150
100
50
0
291
296
301
306
311
Biodiversity
Biodiversity
Current
MAX



Marginal Cost Curve for Imperied Species
Millions $1995
450
400
350
300
250
200
150
100
50
0
3
3.5
4
4.5
5
5.5
Imperiled Diversity Index
Imperiled Diversity

Appendix 8.

Population index values, P_s, for seven land allocation opportunities.

		Original Allocation Allocation	2025 Allocation	B = 20mil Allocation	Max Bio Allocation	Imperiled B = 20mil Allocation	Imperiled Max Bio Allocation
Ambystoma	Gracile	4998.5	2199.296	5338.008	5655.947	3371.515	2839.609
Ambystoma	macrodactyl	5001.8	4960.951	5302.039	5288.609	4952.11	5029.55
Aneides	ferreus	4999.5	2438.724	5660.755	6153.024	4752.401	4002.641
Ensatina	eschscholtzii	5001.2	3738.416	4647.034	4861.387	2708.077	2326.877
Plethodon	dunni	5001.7	1819.121	4755.076	5115.057	3576.257	3012.05
Plethodon	vehiculum	5000.4	2271.647	4490.024	4841.404	3491.072	2940.305
Taricha	granulosa	4999.9	4051.518	5043.68	5228.723	3493.493	3265.797
Dicamptodon	tenebrosus	1499.6	581.098	1467.933	1568.302	1023.709	862.204
Ascaphus	truei	1500.4	168.928	1773.038	1925.202	1443.654	1215.896
Pseudacris	regilla	5000.9	4637.928	5406.409	5389.26	4468.216	4415.999
Rana	aurora	1501.2	892.5	1588.243	1652.506	1227.793	1166.305
Ardea	herodias	5001.1	3051.368	6414.303	6547.193	4854.42	4713
Butorides	virescens	4999.6	3822.128	4753.41	4948.11	2427.013	2044.116
Branta	canadensis	151.3	159.794	172.3	166.602	268.436	281.611
Aix	sponsa	5000.4	4463.485	7857.8	7660.78	0	0
Anas	Platyrhynch	4999.4	5040.59	5694.303	5726.625	9032.594	9887.091
Lophodytes	Cucullatus	4999.8	3136.818	7709.753	7807.914	2140.075	1802.447
Cathartes	Aura	5001.4	5974.824	5030.705	5127.933	3969.405	3979.456
Pandion	Haliaetus	5000	2345.113	13819.53	14173.22	13902.26	10286.03
Elanus	Leucurus	625	621.963	742.584	743.37	1001.023	1095.721
Haliaeetus	Leucocephal	1499.8	143.443	2672.221	2927.627	2367.234	1993.768
Circus	Cyaneus	5000.2	6570.204	4821.802	4812.602	6614.235	7239.951
Accipiter	striatus	4998.9	3265.116	4412.832	4585.466	3049.745	2737.073
Accipiter	cooperii	5000.8	3159.728	4966.665	5087.128	3016.239	2599.318
Accipiter	gentilis	624.6	0	690.468	765.156	675.499	568.929
Buteo	jamaicensis	5000.6	5433.006	5257.06	5280.15	4167.36	4171.318
Aquila	chrysaetos	5001.6	8041.699	4833.824	4959.832	4242.115	4204.42
Falco	sparverius	5000.9	6298.065	5340.6	5083.004	6068.407	6215.913
Dendragapus	obscurus	4999.8	3774.993	4362.014	4652.22	3083.083	2596.682
Bonasa	umbellus	4999.2	4538.515	4414.421	4537.45	1866.588	1572.106
Oreortyx	pictus	1499	2606.987	1187.592	1153.323	397.603	435.216
Charadrius	vociferus	5000.3	6042.832	5635.347	4756.385	8549.089	7680.288
Gallinago	gallinago	4999.4	5040.59	5694.303	5726.625	9032.594	9887.091
Brachyramph	marmoratus	149.9	0	496.465	550.168	485.701	409.075
Columba	fasciata	4999.2	3698.318	4354.327	4542.033	2307.65	1944.765
Zenaida	macroura	4999.9	7233.75	4614.522	4468.743	5081.657	5365.961
Tyto	alba	5001.1	5291.052	6101.815	5785.299	8555.647	8532.473
Otus	kennicottii	4999.7	3884.378	5121.88	5253.149	2617.098	2107.05
Bubo	virginianus	4998.8	3889.508	5545.961	5678.844	4555.331	4364.57
Glaucidium	gnoma	1500.4	754.429	1475.501	1577.535	1046.126	881.084
Athene	cunicularia	150.2	151.4	171.035	172.006	271.305	296.971
Strix	occidentalis	624.6	0	919.606	1019.08	899.668	757.733
Strix	varia	5000.1	1652.873	7275.659	7674.952	4271.183	3597.342
Asio	otus	1500.3	1519.186	1187.623	1192.84	306.366	258.032
Asio	flammeus	1499	1511.394	1707.406	1717.098	2708.375	2964.591

		Original Allocation Allocation	2025 Allocation	20 million Allocation	Max Bio Allocation	Imperiled 20 million Allocation	Imperiled Max Bio Allocation
Aegolius	acadicus	1499.5	647.927	1587.304	1685.478	1029.687	867.239
Chordeiles	minor	5000.7	9795.762	2848.807	2769.533	2221.896	2432.091
Chaetura	vauxi	5000	2345.113	13819.53	14173.22	13902.26	10286.03
Calypte	anna	1500.4	1515.402	2273.145	2080.024	238.786	0
Selasphorus	rufus	5000.5	5497.079	4103.183	4087.816	1850.571	1393.372
Melanerpes	lewis	1500.1	1339.046	2357.34	2298.234	0	0
Melanerpes	formicivorus	626.6	559.636	983.572	959.001	4.678	5.12
Sphyrapicus	ruber	1500.8	871.699	1575.584	1606.396	862.802	673.4
Picoides	pubescens	1500.6	1935.009	1879.343	1756.33	124.458	0
Picoides	villosus	1499.7	689.045	1680.897	1783.53	1080.499	910.034
Colaptes	auratus	5000.5	4744.237	5115.674	4948.721	3871.414	3337.148
Dryocopus	pileatus	1500.1	625.085	1616.627	1734.702	1183.617	996.884
Contopus	borealis	1500.1	902.347	1409.922	1527.02	1156.717	974.228
Contopus	sordidulus	1500.4	1649.327	1641.949	1576.061	428.514	268.101
Empidonax	traillii	1500.2	3390.989	587.266	552.411	0	0
Empidonax	hammondii	1499.5	1270.443	837.625	888.345	581.347	489.631
Empidonax	difficilis	1500.8	644.584	1525.545	1607.509	966.701	803.045
Tyrannus	verticalis	4998.9	4989.297	5883.914	5896.067	8237.389	9016.658
Eremophila	alpestris	4999.4	5040.59	5694.303	5726.625	9032.594	9887.091
Progne	subis	625.2	564.452	1343.26	1472.71	1222.473	1029.61
Tachycineta	bicolor	5000.9	5657.461	5299.831	5367.176	2492.694	2353.24
Tachycineta	thalassina	5001.5	9700.62	3183.458	2682.877	2700.469	2160.721
Hirundo	pyrrhonota	5000.1	9524.51	5426.52	1378.756	6861.744	0
Hirundo	rustica	5000.6	6431.078	5612.451	4380.432	8361.678	6825.216
Cyanocitta	stelleri	4999.6	4464.121	4203.031	4448.569	2754.301	2319.769
Aphelocoma	californica	4999.2	5395.92	7128.554	6320.462	2487.297	1464.375
Corvus	brachyrhync	5000.9	5868.487	5628.817	5244.679	7145.272	7122.187
Corvus	corax	1500.6	733.575	1689.352	1810.361	1491.238	1336.246
Parus	atricapillus	5000	5660.663	6140.553	5690.851	1205.836	482.079
Parus	rufescens	5000.8	3246.337	4151.979	4412.667	3262.111	2673.462
Psaltriparus	minimus	4999.7	8612.215	4276.699	3932.381	935.032	619.543
Sitta	canadensis	5000.1	2407.33	4560.697	4842.622	3477.125	2849.679
Sitta	carolinensis	1499.7	1381.954	2335.835	2243.797	58.715	0
Certhia	americana	1499.6	544.77	1755.949	1855.32	1142.333	949.054
Thryomanes	bewickii	1501.5	2330.628	1254.557	1193.614	135.238	107.524
Troglodytes	aedon	1498.9	2334.392	1318.359	1222.781	349.891	211.91
Troglodytes	troglodytes	1499.3	1244.311	1320.836	1395.842	841.384	708.644
Regulus	satrapa	1500.4	754.429	1475.501	1577.535	1046.126	881.084
Sialia	mexicana	1498.5	2269.275	1351.694	1303.37	1210.715	1269.808
Catharus	ustulatus	5000.6	4360.209	4009.628	4200.628	2305.961	1942.162
Turdus	migratorius	5001.1	5497.596	4660.798	4584.637	3751.153	3600.248
Ixoreus	naevius	1499.8	177.666	1750.231	1897.878	1406.292	1184.429
Chamaea	fasciata	4999.7	10201.66	2905.496	2776.343	0	0
Bombycilla	cedrorum	5001.3	7577.527	5138.829	4645.308	1794.966	1269.808
Vireo	solitarius	1498.9	1270.751	1558.658	1563.925	354.188	298.31

		Original Allocation Allocation	2025 Allocation	20 million Allocation	Max Bio Allocation	Imperiled 20 million Allocation	Imperiled Max Bio Allocation
Vireo	huttoni	1499.6	616.381	1467.137	1526.736	717.344	604.172
Vireo	gilvus	4999.6	6180.349	6476.007	6094.662	359.11	0
Vermivora	celata	5000.1	8189.659	4660.53	4470.579	64.917	0
Dendroica	petechia	1500.1	1339.046	2357.34	2298.234	0	0
Dendroica	coronata	5000.4	544.647	5585.886	6062.352	4526.737	3812.578
Dendroica	nigrescens	5000.4	4243.184	5222.778	5238.715	1173.156	988.073
Dendroica	occidentalis	1500.4	536.136	1416.289	1526.167	1084.982	913.81
Oporornis	tolmiei	1500.6	3008.022	918.433	879.035	0	0
Geothlypis	trichas	5000.2	4888.042	6268.776	6240.268	6637.623	7265.552
Wilsonia	pusilla	4999.2	5897.729	2080.772	1997.551	0	0
Icteria	virens	1500.1	1339.046	2357.34	2298.234	0	0
Piranga	ludoviciana	5000.3	2409.694	4747.295	4996.331	2766.256	2329.839
Pheucticus	melanoceph	4999.8	2686.719	5773.9	5950.744	2400.112	2021.459
Passerina	amoena	1498.8	1383.4	2185.151	2144.145	711.007	778.269
Pipilo	maculatus	1501	2198.818	1342.416	1257.054	458.022	404.495
Spizella	passerina	1500	1975.551	1683.105	1597.608	918.372	901.154
Poecetes	gramineus	1499.8	1498.354	1760.191	1764.388	2493.202	2729.062
Passerculus	sandwichen	5000.9	5029.68	5742.604	5769.997	8840.809	9677.163
Ammodramus	savannarum	149.6	147.869	181.284	181.091	224.528	245.769
Melospiza	melodia	5001.3	6911.8	4267.832	4067.503	3008.177	2900.883
Zonotrichia	leucophrys	4999.6	7977.346	4346.537	4101.737	3323.803	3323.005
Junco	hyemalis	5001.6	4626.5	3605.728	3631.591	2343.066	2174.443
Agelaius	phoeniceus	4999.9	5019.815	5774.632	5798.502	8700.479	9523.557
Sturnella	neglecta	1501.4	1503.039	1750.327	1755.769	2544.656	2785.384
Euphagus	cyanocephal	4999.4	5471.419	5799.762	5393.46	8249.615	8248.629
Molothrus	ater	5000.4	5731.503	4729.265	4637.901	3821.601	3831.089
Icterus	bullockii	1499.5	2209.212	1656.488	1503.897	182.139	0
Carpodacus	purpureus	1500.7	1148.414	1259.216	1310.253	645.609	543.755
Carpodacus	mexicanus	5001.4	5554.37	6565.964	5812.992	4848.232	4039.831
Loxia	curvirostra	1499.5	390.022	1472.692	1588.264	1129.816	951.571
Carduelis	pinus	4999.6	3592.023	4320.761	4639.758	3284.836	2766.605
Carduelis	psaltria	1500.7	1484.852	2022.995	1947.554	1358.953	1392.692
Carduelis	tristis	1500.7	2129.118	1498.555	1429.295	1176.032	1198.125
Coccothrauste	vespertinus	4999.6	1592.13	5687.539	6138.52	4402.696	3708.107
Sorex	vagrans	1500.3	1471.447	1566.363	1574.749	1343.411	1361.049
Sorex	pacificus	623.3	594.846	574.864	591.325	246.587	207.684
Sorex	bendirii	1499.1	1439.072	1293.899	1342.479	647.104	545.014
Sorex	trowbridgii	1500.7	1443.966	1259.575	1311.823	669.521	563.894
Sorex	sonomae	5000.2	4781.458	4510.043	4652.381	2039.946	1718.115
Neurotrichus	gibbsii	1500.3	1144.016	1634.643	1704.011	844.373	711.161
Scapanus	townsendii	1499.7	1548.983	1726.922	1669.264	2010.642	2058.209
Scapanus	orarius	4999.3	4823.307	4537.437	4678.13	2961.359	2771.575
Myotis	lucifugus	1498.7	1307.127	1605.872	1613.155	1495.253	1385.067
Myotis	yumanensis	625.8	501.366	799.674	820.134	725.128	659.987
Myotis	evotis	627	614.211	571.723	583.115	427.774	401.334

		Original Allocation Allocation	2025 Allocation	20 million Allocation	Max Bio Allocation	Imperiled 20 million Allocation	Imperiled Max Bio Allocation
Myotis	thysanodes	627.3	469.231	668.352	703.042	562.801	524.772
Myotis	volans	623.4	312.776	900.717	961.836	811.854	740.435
Myotis	californicus	1499.5	1163.397	1635.195	1698.8	1375.636	1293.285
Lasionycteris	noctivagans	1499.4	1403.591	1900.817	1970.052	1639.978	1490.985
Eptesicus	fuscus	1500.6	1463.469	1869.516	1889.113	1802.441	1662.856
Lasiurus	cinereus	1499.7	917.844	2179.667	2275.813	1752.634	1562.025
Plecotus	townsendii	1500.8	1280.033	1436.193	1455.221	1134.58	1030.857
Antrozous	pallidus	624.8	664.035	781.434	728.925	797.761	783.389
Sylvilagus	bachmani	5000.4	4803.681	4804.025	4917.943	2895.781	2744.676
Lepus	americanus	1499.9	1653.545	1097.428	1125.049	467.768	393.971
Lepus	californicus	1499.9	1507.066	1727.777	1735.417	2628.854	2877.548
Aplodontia	rufa	1500.6	1562.216	947.193	968.044	561.501	524.857
Tamias	townsendii	1500.3	1493.754	1312.874	1366.031	687.454	578.998
Spermophilus	beecheyi	5000.3	5157.387	5943.522	5779.812	7861.279	8294.711
Sciurus	griseus	1498.5	538.582	1760.908	1811.163	899.012	723.748
Tamiasciurus	douglasii	5000.2	609.451	5473.889	5923.039	4305.556	3626.292
Glaucomys	sabrinus	1499.9	359.326	1606.717	1670.262	1147.247	903.741
Thomomys	mazama	4998.2	6162.439	2502.264	2442.685	1660.575	1817.668
Thomomys	bulbivorus	1499.9	1559.57	1740.569	1694.733	2533.463	2677.86
Castor	canadensis	5000.6	4930.471	4854.695	4906.94	4240.121	4178.397
Peromyscus	maniculatus	5000.1	4888.549	4754.134	4829.912	3574.998	3429.46
Neotoma	fuscipes	1500.1	1339.046	2357.34	2298.234	0	0
Neotoma	cinerea	4999.7	4796.851	4342.48	4501.743	2141.57	1803.706
Clethrionomys	californicus	1500	820.371	1593.502	1693.97	1056.587	889.895
Phenacomys	albipes	626.3	676.315	477.787	498.75	269.004	226.565
Phenacomys	longicaudus	1500.2	0	2208.888	2447.822	2160.998	1820.069
Microtus	townsendii	1500.8	1477.029	1844.492	1839.865	2147.054	2350.168
Microtus	longicaudus	5000.3	10083.35	3008.922	2878.342	0	0
Microtus	oregoni	1499.7	1805.668	944.684	959.329	352.694	297.051
Microtus	canicaudus	4998.9	4973.701	5942.079	5948.058	7994.15	8750.408
Zapus	trinotatus	1500.1	978.816	1576.727	1662.661	951.975	801.787
Erethizon	dorsatum	5000.8	4810.079	4432.915	4583.708	2515.051	2244.577
Canis	latrans	4999.3	5204.854	4703.496	4704.198	4155.956	4127.605
Vulpes	vulpes	1500	1613.286	1572.054	1547.256	1515.496	1593.616
Urocyon	cinereoarge	1499.9	1326.75	1381.757	1443.447	754.705	635.639
Ursus	americanus	1499.2	1446.788	1357.852	1394.091	752.013	664.976
Procyon	lotor	4999.9	5001.246	4654.517	4624.69	3126.964	2695.393
Martes	americana	624.9	541.624	578.37	610.537	363.155	305.862
Martes	pennanti	149.8	105.836	139.592	149.765	104.613	88.108
Mustela	erminea	4999.7	4811.727	4604.877	4738.629	2804.783	2605.468
Mustela	frenata	4999.7	4811.727	4604.877	4738.629	2804.783	2605.468
Spilogale	gracilis	1499.3	1623.093	1300.006	1332.804	538.008	453.129
Mephitis	mephitis	4999.6	6597.104	5722.794	5574.678	4607.876	4499.847
Felis	concolor	1500.4	1629.618	1425.639	1440.5	1183.657	1190.482
Lynx	rufus	1500.5	1479.325	1363.537	1383.722	918.165	871.663

		Original Allocation Allocation	2025 Allocation	20 million Allocation	Max Bio Allocation	Imperiled 20 million Allocation	Imperiled Max Bio Allocation
Cervus	elaphus	5000.3	5369.89	4975.793	5049.404	4919.169	5074.584
Odocoileus	hemionus	4997.9	5440.558	4813.339	4822.916	4280.424	4287.761
Chrysemys	picta	150.3	149.999	176.801	177.174	247.917	271.37
Clemmys	marmorata	150.4	150.425	175.904	176.39	252.595	276.49
Elgaria	coerulea	5000	6435.796	3897.16	3908.301	2199.728	1912.243
Elgaria	multicarinata	4999.2	6830.35	5448.118	5155.213	2803.753	2713.702
Sceloporus	occidentalis	4999.8	8138.1	2785.028	2545.251	239.381	15.361
Eumeces	skiltonianus	5000.4	8332.108	4689.414	4180.147	676.924	51.202
Charina	bottae	1498.5	1923.064	1326.215	1301.599	736.791	663.7
Coluber	constrictor	1499.3	1510.235	1595.241	1564.789	1379.843	1343.598
Contia	tenuis	624.1	662.125	651.795	641.54	361.084	332.106
Diadophis	punctatus	1501.1	1493.474	1537.589	1518.151	1042.024	958.131
Pituophis	catenifer	4999.7	5926.449	5293.099	5061.158	5481.481	5470.877
Thamnophis	ordinoides	4999.9	5714.739	4313.718	4197.46	3496.069	3363.272
Thamnophis	sirtalis	4999.7	5451.373	4962.224	4838.208	4630.627	4454.147
Crotalus	viridis	1501.2	1421.407	2054.474	2027.626	1272.328	1392.692