Inventory and monitoring of biodiversity : an assessment of methods and a case study of Glacier National Park, MT
by Diane Marie Debinski

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biological Sciences
Montana State University

Abstract:
Biodiversity is currently threatened around the world, yet humankind knows little about its distribution or rates of loss. Because biodiversity can be defined at the level of species, habitats, or genes, temporal changes can be assessed at several different levels. These changes may indicate responses to natural disturbances, human-induced changes, or long-term environmental trends. However, no standard analysis techniques for biodiversity assessment have yet been developed. In order to protect biodiversity or to use it as an indicator of environmental change, baseline data must be collected and analysis techniques must be developed.

This research applies and evaluates sampling and analysis techniques for inventory and monitoring of biodiversity. Glacier National Park is used as a case study. Birds and butterflies were chosen to demonstrate species diversity inventory. The butterfly, Euphydryas gillettii, was used to demonstrate genetic diversity assessment.

Biodiversity assessment sites were established throughout a range of habitats and monitored during the summers of 1987, 1988 and 1989. Thirty-three sites were monitored for birds and twenty-four sites were monitored for butterflies. Presence/absence sampling was used to classify species commonness and rarity. Goals accomplished included 1) describing the current species composition, 2) identifying diversity hotspots and sites supporting rare species, and 3) creating a baseline for assessing change.

A discourse on biodiversity assessment would not be complete, however, without addressing the problems inherent in biodiversity assessment and management. Replication in both time and space is necessary to distinguish natural background variation in species distribution from true changes and sampling artifact. It is often difficult to reconcile the need for sampling replication within a habitat type with the need to survey a large, highly diverse ecosystem. Further, it is extremely difficult to use biodiversity as an environmental indicator unless relationships between species and environmental changes are specific and well-understood. Finally, management for biodiversity requires a large-scale perspective on ecosystem management and a modest understanding of the natural history of the species examined. Unless biodiversity assessments are done thoroughly and carefully, they will have limited descriptive or predictive value.

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Date 1 June 1991

"For someone studying natural history,
life can never be long enough"

Miriam Rothschild, British Entomologist,
television interview on Nova, 1986

VITA

Diane Debinski was born in Baltimore, Maryland on October 26, 1962. She became fascinated by natural history at the age of nine on her first trip to the mountains of western Maryland. She earned a dual B.A degree in Biology and Environmental Studies in 1984 from the University of Maryland at Baltimore County. She went on to find her fundamental niche at the University of Michigan's School of Natural Resources. There she studied Natural Resource Policy, Economics, and Management, hoping to gain a broader perspective on conservation issues. Her thesis was entitled "Using Decision Analysis to Improve Recovery Planning for Endangered Species", and she obtained her M.S. in 1986. She took a year's sabbatical from academia after the M.S., spending time studying crested auklets in the Aleutian Islands, AK, then studying politics in Washington, D.C. Next stop was Bozeman, MT for a degree in Conservation Biology. The Bozeman program led her into this research project at Glacier National Park, three years of incredible field work which included a few grizzly encounters. But the bears didn't put too much of a damper on data collection; they simply added some spice to the backcountry camping. If given the option, she'd do it all over again in an instant.

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TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1
	Threats to Biodiversity	1
	The Value of Biodiversity	3
	Hotspots of Biodiversity	4
	Preserving Biodiversity	5
	Biodiversity and Ecosystem Stability	7
	Methods of Biodiversity Assessment	8
	The Case Study	15
	Glacier National Park	15
	Research Goals	17
2.	SPECIES DIVERSITY ASSESSMENT IN GLACIER NATIONAL PARK, MONTANA	18
	Introduction	18
	Describing the Data	21
	Species/Habitat Assemblages	21
	Sampling Efficiency Analysis	22
	Management Implications	23
	Methods	23
	Criteria for Choice of Groups	23
	Census Sites	26
	Qualitative Sampling	34
	Habitat Characterization in Sample Sites	36
	Presence/Absence Sampling	38
	Evaluating Biodiversity Data	40
	Describing the Data	40
	Species/Habitat Assemblages	40
	Sampling Efficiency Analysis	41
	Results	41
	Describing the Data	41
	Historic Species Lists	41
	Analysis of Commonness & Rarity	43
	Rank Occurrence Analysis	54
	Sites Supporting Rare Species	58
	Diversity Hotspots	63

TABLE OF CONTENTS--Continued

Page

Species/Habitat Relationships 68
Species Assemblage Analysis - PCA & Cluster Analysis 68
Butterfly 1988 PCA. 69
Bird 1988 PCA 73
Butterfly 1989 PCA. 76
Bird 1989 PCA 76
ANOVA and Discriminant Analysis for Species/Habitat Associations . . 83
Gradient Analysis. 85
Elevation Gradients 85
Moisture Gradients. 88
Edge Effects 88
Habitat Diversity and Species Richness 91
Sampling Efficiency Analysis. 100
Spatial and Temporal Fluctuations in Species Distribution and Diversity .100
G-Test for Changes between Years . . .102
Cost/Benefit Analysis of Sampling Effort 103
Discussion 106
Describing the Data 106
Historic Species Lists 106
Reliability of Species Diversity Data 107
Analysis of Commonness & Rarity. . . .108
Analysis of Rarity 110
Rank Occurrence Analysis 111
Diversity Hotspots 113
Species/Habitat Relationships 113
Species Assemblage Analysis - Principal Components Analysis. . . .113
Species Assemblage Analysis - Cluster Analysis 115
ANOVA and Discriminant Analysis for Species/Habitat Associations 115
Gradient Analysis. 116
Elevation Gradients 116
Moisture Gradients. 117
Edge Effects 117
Habitat Diversity and Species Richness 118
Sampling Efficiency Analysis. 119
Spatial and Temporal Replication . . .119
Cost/Benefit Analysis of Sampling Effort 120
Monitoring 121

TABLE OF CONTENTS--Continued

Page

Suggestions for Future Research at Glacier .124
Additional Taxa to be Included 124
Using the GIS in Concert with Present Biodiversity Data. 128
Summary. 130
Species Detection 130
Habitats of Significance. 130
Techniques for Analyzing Biodiversity Data. .132
Recommendations for future Biodiversity Inventories 133
Conclusions. 134

3. GENETIC DIVERSITY ASSESSMENT. 137

Introduction 137
Choosing Species for Genetic Diversity Assessment. 138
Estimating Genetic Diversity. 141
Metapopulations. 144
Definition. 144
Relevance of Metapopulations to Conservation Biology. 146
Life History of *E. gillettii* 147
Research Plan/Methodology. 150
Results. 151
Colonies. 151
Population Sizes. 152
Genetic Analysis. 153
1988 Results 154
Heterozygosity. 154
Wright's Inbreeding Coefficients. 156
Chi-Square Analysis 156
Genetic Identity. 156
1989 Results 157
Heterozygosity. 157
Wright's Inbreeding Coefficients. 160
Chi-Square Analysis 161
Genetic Identity. 162
Discussion .167
Colony Numbers and Distribution 167
Genetic Diversity 168
F-Statistics and Genetic Similarity 172
Implications for Management 173
Summary. 177

TABLE OF CONTENTS--Continued

Page

4. PROBLEMS IN BIODIVERSITY ASSESSMENT AND MANAGEMENT. 179

Problems Inherent in Assessing Biodiversity. . . .180
Sampling Problems in Biodiversity Assessment. 180
Spatial Scales. 181
Habitat Heterogeneity 184
Habitat Site Selection. 184
Sampling Effort and Replication 186
Rare Species. 188
Presence/Absence Sampling 189
Reliability of Species Diversity Data . . .191
Detectability Profile 192
Permanent versus migratory species. 193
Natural Fluctuations. 193
Monitoring. 194
Summary of Sampling Problems. 195
Biodiversity as an Indicator of Environmental Change .196
Indicator Species vs. Indicator Taxa. . . .196
Birds and Butterflies as Indicator Taxa . .199
The Relationship Between Diversity and Stability 201
Additional Considerations in Managing for Biodiversity 202
Sources & Sinks 202
Reserve Boundaries. 203
Summary. 205

LITERATURE CITATIONS. 206

APPENDICES. 216

Appendix A - Description of Sample Sites 217
Appendix B - Presence/Absence Matrices for Each Year 235
Appendix C - Starch Gel Electrophoresis Methodology. 254
Appendix D - 1988 Data - Allele Frequencies and Genetic Variability Measures 256
Appendix E - 1989 Data - Allele Frequencies and Genetic Variability Measures 260

LIST OF TABLES

Table Page

1. Summary of Intensive Sampling Procedure . . . 36
2. Comparison of Historic Species Assemblages with Species Found in Biodiversity Sampling . . . 43
3. Total Annual Species Occurrences - Butterflies . . . 44
4. Total Annual Species Occurrences - Birds . . . 49
5. Common Birds Under-represented in GNP Census . . . 54
6. Habitats Supporting Rare Species - Butterflies 1989 . . . 59
7. Habitats Supporting Rare Species - Birds 1989 . . . 59
8. Sites Supporting Rare Species . . . 60
9. Diversity Between Census Sites - Butterflies . . . 63
10. Diversity Between Census Sites - Birds . . . 64
11. Diversity Hotspots 1989 - Butterflies . . . 65
12. Diversity Hotspots 1989 - Birds . . . 66
13. Habitat ANOVA Results 1989 - Butterflies . . . 83
14. Habitat ANOVA Results 1989 - Birds . . . 84
15. Moisture Gradient Analysis 1987 - Butterflies . . . 88
16. Forest Edges and Butterfly Diversity . . . 90
17. Forest Edges and Bird Diversity . . . 90
18. Index of Biotic Similarity - Birds . . . 101

LIST OF TABLES--Continued

Table Page

19. Index of Biotic Similarity - Butterflies . . .102
20. Sample Size Necessary for Detecting Rare Species .105
21. Characteristics of 15 sites occupied by *Euphydryas gillettii*. 148
22. Enzymes used in Genetic Analysis of *Euphydryas* spp. 151
23. Colony Sizes and Mark-Recapture Data for *E. gillettii* in Glacier National Park Ecosystem - Summer 1989 153
24. Sample sizes for electrophoresis 154
25. Polymorphic Loci of *E. gillettii* -1988. 155
26. Summary of F-Statistics - all Loci in Belly River and Christensen Meadow - 1988 156
27. Contingency Chi-Square Analysis - all Loci 1988 157
28. Polymorphic Loci of *E. gillettii* - 1989 158
29. Heterozygosity at Variable Loci - 1989 . . .160
30. Summary of F-Statistics over all Loci within MT, WY, and ID - 1989. 160
31. Contingency Chi-Square Analysis - all Loci, all populations 1989. 161
32. Contingency Chi-Square Analysis - all Loci, Glacier populations 1989. 162
33. Contingency Chi-Square Analysis - Belly River 1988 and 1989 162
34. Matrix of Genetic Similarity and/or Distance Coefficients - Nei (1978). 163
35. Matrix of Genetic Similarity and/or Distance Coefficients - Rogers (1972) . . .167

LIST OF TABLES--Continued

Table Page

36. Electrophoretic Results: Belly River 1988. 257
37. Electrophoretic Results: Christensen Meadow 1988 .258
38. Electrophoretic Results: Idaho 1989 261
39. Electrophoretic Results: Belly River 1989. 262
40. Electrophoretic Results: Red Meadow 1989. 264
41. Electrophoretic Results: Marias Pass 1989. 265
42. Electrophoretic Results: Wyoming 1989. 267
43. Electrophoretic Results: All Populations 1989. 268

LIST OF FIGURES

Figure | Page

1. Habitat Types - Butterfly Biodiversity Sites 1987. 28
2. Habitat Types - Bird Biodiversity Sites 1987. 29
3. Glacier National Park, MT Biodiversity Sampling Sites. 30
4. Habitat Types - Bird Biodiversity Sites 1988-1989 32
5. Habitat Types - Butterfly Biodiversity Sites 1988-89 33
6. Species Effort Curve - Butterflies 1988. . . 35
7. Standard Rank Abundance Curve. 55
8. Rank Occurrence - Birds 1989 56
9. Rank Occurrence - Butterflies 1989 57
10. Replication and Richness - Butterflies 1989. 67
11. Butterfly PCA - 1988 70
12. Butterfly PCA - 1988 71
13. Butterfly Cluster Analysis - 1988. 72
14. Bird PCA - 1988. 74
15. Bird PCA - 1988. 75
16. Butterfly PCA - 1989 77
17. Butterfly PCA - 1989 78
18. Butterfly Cluster Analysis - 1989. 79
19. Bird PCA - 1989. 80

LIST OF FIGURES--Continued

Figure Page

20. Bird PCA - 1989. 81

21. Bird Cluster Analysis - 1989 82

22. Elevation Gradient - Butterflies 86

23. Elevation Gradient - Birds 87

24. GIS Habitat Diversity and Species Richness Birds 1989. 92

25. Elevation Diversity versus Species Richness Birds 1989. 93

26. Aspect Diversity versus Species Richness Birds 1989. 94

27. Slope Diversity versus Species Richness Birds 1989. 95

28. GIS Habitat Diversity and Species Richness Butterflies 1989. 96

29. Elevation Diversity versus Species Richness Butterflies 1989. 97

30. Slope Diversity versus Species Richness Butterflies 1989. 98

31. Aspect Diversity versus Species Richness Butterflies 1989. 99

32. Range of *Euphydryas gillettii*. 140

33. Cluster Analysis - Nei (1978). 165

34. Cluster Analysis - Rogers (1972) 166

ABSTRACT

Biodiversity is currently threatened around the world, yet humankind knows little about its distribution or rates of loss. Because biodiversity can be defined at the level of species, habitats, or genes, temporal changes can be assessed at several different levels. These changes may indicate responses to natural disturbances, human-induced changes, or long-term environmental trends. However, no standard analysis techniques for biodiversity assessment have yet been developed. In order to protect biodiversity or to use it as an indicator of environmental change, baseline data must be collected and analysis techniques must be developed.

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A discourse on biodiversity assessment would not be complete, however, without addressing the problems inherent in biodiversity assessment and management. Replication in both time and space is necessary to distinguish natural background variation in species distribution from true changes and sampling artifact. It is often difficult to reconcile the need for sampling replication within a habitat type with the need to survey a large, highly diverse ecosystem. Further, it is extremely difficult to use biodiversity as an environmental indicator unless relationships between species and environmental changes are specific and well-understood. Finally, management for biodiversity requires a large-scale perspective on ecosystem management and a modest understanding of the natural history of the species examined. Unless biodiversity assessments are done thoroughly and carefully, they will have limited descriptive or predictive value.

CHAPTER 1

INTRODUCTION

Biodiversity is the variety among living things: variety in ecosystems, habitats, species, and genes. Biodiversity is currently threatened around the world, yet humankind knows little about its distribution or rates of loss. In most cases, we don't even understand ways in which biodiversity is important to the human race. The lack of a comprehensive data base to document biological diversity is a major problem. In order to protect biodiversity or to use it as an environmental indicator, baseline data must be collected and analysis techniques must be developed. The goal of the research presented here is to begin to develop techniques for inventorying and monitoring biodiversity.

Threats to Biodiversity

Biodiversity is threatened both in the tropics and in temperate climes. For example, Montana's natural heritage program of the Nature Conservancy is specifically concerned with several globally imperiled species such as the whooping crane, Coeur d'Alene salamander, black footed ferret, piping plover, arctic grayling, and pallid sturgeon (Genter, pers.

comm.).

As Huntley (1989) summarizes the problem, "Neither Darwin nor Wallace could have envisaged that the biological wealth they were revealing to the world at the start of the Industrial Revolution would be heading for destruction within the next century."

Only a few years ago, biologists believed that the earth supported 3 to 5 million species of all living organisms. However, current research in the tropics suggests that there may be 30 million species of insects alone. Many species at risk of extinction are not even known to science, and their ecological roles and potential values to humans are also mysteries (Wolf 1987). The earth is currently losing species at a rate 1,000 to 10,000 times faster than the normal evolutionary rates (Huntley 1989). Not since the Cretaceous Period, about 65 million years ago, has the earth experienced such a high rate of extinction. During mass extinctions the fittest are not necessarily the ones that survive. Survivors tend to be the ecological opportunists, weedy species that reproduce quickly, eat indiscriminantly, and tolerate a wide range of conditions (Wolf 1987).

The threats to biological diversity in any forest, preserve, or park can be separated into two types, exogenous and endogenous. Exogenous threats manifest themselves as acid rain, pesticide drift, exotics, or loss of migratory habitat, and they are initiated from outside the protected area. Endogenous effects occur within the protected area, and include fragmentation and insularization, decreased immigration or elimination of vital resources inside a reserve.

Humans can be regarded as diversity generators through the use of laboratory and agricultural research. The type of diversity generated in this case is genetic diversity. However, the amount of genetic diversity we generate in no way compensates for the amount of species and habitat diversity which is being lost. Indeed, humans do not create genes; we simply re-arrange existing genes. As such, our ability to generate biodiversity should not be overestimated.

The Value of Biodiversity

The Office of Technology Assessment's (OTA) report, "Technologies to Maintain Biological Diversity", sums up the value of biodiversity as follows: "Human welfare is inextricably linked to, and dependent upon, biological diversity". Diversity is necessary to 1) sustain and improve agriculture, 2) provide opportunities for medical discoveries and industrial innovations, and 3) preserve choices for addressing unpredictable problems and opportunities for future generations. Biological diversity is the basis of adaptation and evolution and is intrinsic to all ecological processes. It contributes to research, education, cultural heritage, recreation and tourism, the development of plant and animal domesticates, and the supply of harvested resources (OTA 1987).

Hotspots of Biodiversity

Before we can create management strategies and political policies to protect biodiversity, we must understand its spatial and temporal distribution. Our distribution knowledge gap is evident both in tropical and temperate forests. For example, a recent survey of 19 trees in a Panamanian tropical forest produced 950 species of beetles, 80% of which were previously unknown to science (Reid and Miller 1989). Terrestrial species richness is often correlated with elevation and precipitation. However, regions rich in one taxonomic group are not necessarily rich in other taxonomic groups.

Aspects of rarity can be separated into two categories: endemism and scarcity. Endemic species are found only within a limited geographic area, whereas scarce species may have a wide distribution, but are abundant nowhere. Endemism is commonly associated with areas of high species diversity. Endemic species are particularly vulnerable to extinction as their ranges are often restricted to small areas, and if a population goes extinct, there is a lower probability of recolonization from other areas. Endemic species-are often found on mountains, islands, peninsulas, and other areas where dispersal is restricted by geography or where unique conditions lead to the evolution of specialized characteristics. There are more endemic plant species relative to animal species, probably because of the dispersal limitations of plant species (Reid and Miller 1989).

Scarcity is best exemplified by animals at the top of the food chain, e.g. bears, eagles, sharks, or large cats. The size of their home range limits the density of their populations. Habitat fragmentation can have serious consequences for such organisms, making them much more vulnerable to extinction than more densely populated species.

Preserving Biodiversity

The major reservoirs of biodiversity in the U.S. are in public lands, and the vast majority of protected areas in these lands are the national parks. Indeed, creating parks and nature reserves has been the traditional method of preserving biological diversity worldwide. But setting aside or reserving these land areas is not a complete solution to the problem. Often these reserves are not large enough, and in many developing countries it is extremely difficult to protect them from poachers. Even if establishment of parks and reserves were sufficient, Wolf

(1987) estimates that 1.3 billion hectares would have to be set aside to conserve representative samples of all the earth's ecosystems. Currently 425 million hectares in 3,500 areas worldwide are "protected."

Newmark (1987) conducted a survey of national parks in the Rocky Mountains of the U.S. to analyze species extinction as a function of park area. Parks less than 4000 square km had lost from 23% to 43% of their mammal species since their establishment. Only the largest parks which contained 4000 to 21,000 sq. km had retained a high percentage of their native inhabitants. The loss of species evidently occurred so slowly that it went unnoticed. These results have been criticized, however, due to the disagreements regarding the data (Quinn et al., in press)

MacArthur and Wilson's island biogeography study (1967) demonstrated a direct relationship between the area of an island and the number of species it can sustain. Refuges can be viewed as islands in a sea of inhospitable terrain. Reducing habitat size increases the risk of extinction, while increasing the distance of the island from the nearest source of colonists reduces the chances of recolonization after local extinction. "Faunal collapse" occurs as refuges become more and more isolated by development (timber harvest, housing projects, oil drilling, etc.).

Biodiversity and Ecosystem Stability

No agreement exists among ecologists regarding the relationship between biological diversity and ecosystem function. Three hypotheses have been proposed that underscore this lack of agreement: (1) diversity and function are intimately linked on a one-to one basis, (2) considerable loss of diversity may occur without impairing ecosystem function, or (3) the functional capacity of an ecosystem is likely to be impaired long before diversity declines (Cairns and Pratt 1986).

Species diversity has no consistent relationship with ecosystem productivity. Species-rich tropical rainforests are extremely productive, but so are coastal wetlands that have relatively low diversity. For example, in *Spartina* salt marshes one species provides almost all of the primary productivity. The loss of species can either increase or decrease primary productivity. For example, a loss of mycorrhizal fungi decreases the growth rate of plants on which they depend. Conversely, extirpation of sea urchins and limpets allows an increase of algal productivity in the intertidal zone (Reid & Miller 1989).

Advances in ecology have provided us with some specific relationships, however, that will aid our understanding of how environmental changes affect species diversity and how changes in species diversity affect certain ecosystem processes and function. For example Reid & Miller (1989) outline the following relationships:

(1) Species composition is continually changing in most communities, and species-specific responses to environmental changes do not necessarily occur in congress. Thus, in preserving biodiversity our goal should not always be preservation of the exact present community, but rather maintenance of the species and the ecosystem processes.

(2) Species richness can sometimes be increased by increasing the diversity of habitats within an ecosystem, but this intervention can be a "double-edged sword." Such intervention may result in preserving those species less vulnerable to extinction (i.e., those that thrive in early successional habitats and benefit from disturbance) rather than those at greatest risk (i.e., those that require large tracts of late successional habitats).

(3) Habitat patchiness influences both the composition of species in a ecosystem and the interactions among species. For example, heterogeneous environments tend to have more stable predator-prey or host-parasite interactions, as there are escape patches that prevent total extinction.

(4) Periodic disturbances such as fires, hurricanes, and floods are important in creating patchy environments that foster high species richness and influence the interactions among species. Consequently, preservation of species diversity may require management of the environment so as to preserve natural patterns of succession.

(5) Species richness is influenced by size and isolation of habitat patches, as well as the transition zones between habitats. Such "ecotones" often support species that would not occur in continuous habitats (Lovejoy et al. 1986).

(6) Some communities have "keystone" species which exhibit a disproportionate influence on the characteristics of an ecosystem. In worst case scenarios, local extinction of a keystone species may cause a "cascade effect" whereby other species within the community dwindle in number or are extirpated themselves.

Methods of Biodiversity Assessment

If biodiversity is to be protected, it must be inventoried and monitored. Establishment of an inventory and monitoring program is not an easy task, regardless of the ecosystem. In order to conduct such an assessment, the researcher should be familiar with the landscape and topography of the area, competent in using a suitable and efficient sampling method, have reasonable taxonomic ability, and a realization of the kinds and approximate numbers of samples to be taken in the study (Gauch, 1982).

There have been several attempts to set up biodiversity inventory and monitoring programs, both at the level of a national park survey and at the level of a nationwide survey. Sequoia National Park has a program to sample biodiversity at 3400 Universal Transverse Mercator (UTM) intersections within the park. UTMs are geographic marker lines similar to longitude and latitude lines that are separated by 1 km. The survey concentrates on vegetation analysis, but any bird, mammal, reptile, or amphibians identifiable by sight or sound from within the plot (regardless of distance) are noted. Sampling radius from the UTM intersection varies according to the scale and mobility of each class of organisms. Systematically, each of these sites is being monitored over time, and the information is being integrated into a Geographic Information System (GIS). The most expensive and time-consuming element of this project, as in most biodiversity assessments, is the field inventory. Approximately 500 of the 3400 sites were sampled during the first six years of the project (1985-1991). The budget for this work was approximately $40,000 per year, and there were five employees involved in the sampling (Esperanza, pers. comm.)

A well-established nationwide inventory and monitoring program for species diversity is the breeding bird survey. This standardized survey is conducted throughout the U.S. at various sites twice a year. Volunteers travel designated roads, stopping every 1/2 mile to conduct an audio and visual census for 3 minutes. The resulting databases are invaluable for detecting large-scale regional trends. These surveys, however, do not provide the level of sampling intensity necessary to monitor bird populations in a reserve such as Glacier National Park. For example, there are only three regions within this park that are surveyed in the breeding bird survey (Babb, Polebridge, and a portion of the Going to the Sun highway), and all of these sites are along roads. Wilderness areas are neglected, and a large portion of the park is ignored. Further, based upon the results of this research, three minutes twice a year does not approach the amount of time necessary to conduct a thorough census.

Noss (1990b) proposes a heirarchical framework for choosing biodiversity indicators on a nationwide scale. Proceeding from top down, inventories should start at the regional landscape scale and progress down to the levels of community-ecosystem, population-species and genetics. A GIS system would be used to integrate existing data and establish baseline conditions. For example, ecosystem and species distribution maps would be overlain with maps of distribution and intensity of stressors (road density, grazing, habitat fragmentation). Hot spots and ecosystems of high risk would be identified based upon their species richness, endemism, and risk to impoverishment due to anthropogenic stressors. Noss notes that selection of indicators would be based upon the question to be answered, but provides no specifics. He also suggests that a rigorous sampling scheme should be developed using controls (e.g., wilderness areas) and treatments (national forests). This is a good starting point, but the details of implementation are still quite vague. Details of current databases and information availability are left undiscussed.

Gap analysis (Davis et al. 1990, Scott 1987) is an approach that has been implemented in Idaho and California, and offers a more tangible solution to biodiversity inventory and monitoring on a state or national scale. The technique of gap analysis focuses on identifying centers of endemism, species richness, and vegetation diversity, and then identifying gaps in the distribution of protected areas. The analysis can be conducted at several scales, including biogeographic, regional, and local. A GIS is used to compare the locations of species richness with the locations of existing reserves to show where biodiversity is already well protected and where additional reserves will do the most good. Species distribution is predicted from a knowledge of habitat associations and distribution of vegetation types or based upon published literature. Gap analysis can be used to calculate the proportion of threatened or endangered species in existing reserves, to identify the species or habitat types that are not protected by reserves, or to determine whether adequate corridors exist between areas of high species richness. Scott et al. (1989) estimated that a gap analysis of vegetation, vertebrates and butterflies could be completed nationwide within four years at a total cost of $20 to $25 million The Nature Conservancy uses a two-pronged approach for their land management and acquisition programs. A "coarse filter" is used to conduct a community-level assessment of preservation status to identify communities that need to be preserved. Then a "fine filter" is used to identify habitats for threatened, endangered, and rare species. In this way, both habitats and species are considered.

The newest proposal to solve the biodiversity assessment problem is that of "rapid assessment." Rapid assessment is a technique for quickly surveying an ecosystem's complement of plants and animals and recommmending steps for their protection. It focuses on identifying hotspots of biodiversity as conservation priorities. The advantage of this technique is that it brings the challenge of biodiversity preservation down to manageable proportions. The disadvantages are that it may distract policymakers from the need for better management on all wildland areas or the need to support long-term ecological studies (Wolf 1991). However, rapid assessment may be the the best available for the present time in tropical forests which are quickly being destroyed.

The problems associated with these large-scale techniques are numerous. Data quality in terms of low spatial resolution, uneven spatial coverage, currency of dynamic features and map accuracy is of utmost importance. Besides this cartographic uncertainty, the ecological relationships used to estimate species presence are not always rigorous. Even if the habitat is perfectly suitable, the species may not be present. Finally, locating and consolidating the data can be quite costly and time consuming (Davis et al. 1990).

In summary, although the level of detail differs, each of the aforementioned techniques has the same goal: to acquire a detailed description of the species composition, and habitat zones in the area under consideration. By documenting changes in biodiversity over time, scientists will be able to assess the status of an ecosystem. In doing so, some of the questions regarding diversity and stability may be answered, and we may learn to distinguish biodiversity changes induced by natural effects relative to those induced by humans.

An inventory and monitoring program must meet several criteria in order to accomplish these goals. It must track a wide variety of taxonomic groups and representatives of different guilds. It necessarily should be conducted on a large spatial scale so that a full array of habitat types are described. Information on species distribution and abundance should be collected so that clear-cut levels of commonness and rarity can be assessed. The program must be carried out over the course of several decades or more so that background noise (i.e, fluctuations due to variations between years) can be distinguished from variation caused by human-induced events.

Logistical considerations in biodiversity assessment include scale, intensity, precision, and scope. Higher costs are obviously associated with more thorough assessments. Taxonomic groups should be prioritized, as it would be impossible to monitor every single species or taxon around the globe. Finally, regional or nationwide biodiversity assessments should involve major database integration and should be incorporated into a GIS. It may be easier to begin at a small-scale level prior to establishing a nationwide biodiversity database. For this reason, this research focuses on a small-scale level, specifically in one park in Montana, Glacier National Park.

The Case Study

Glacier National Park

Glacier National Park is one of the most pristine parks in the United States. Its 4000 square km encompass elevation ranges from 1097 m to 3048 m. The west side of the park is a temperate rainforest with cedar/hemlock (*Thuja plicata*/*Tsuga heterophylla*), spruce/fir (*Picea englemanii*/*Pseudotsuga menzeisii*) and lodgepole pine (*Pinus contorta*) stands, while the east side is drier and windier, with aspen (*Populus tremuloides*) parklands and sagebrush (*Artemesia tridentata*) meadows. Habitat types include alpine meadows, bogs, and rocky ridges, riparian corridors, low elevation meadows, ponderosa pine stands, lodgepole pine, spruce/fir, and cedar/hemlock dominated forests.

Ecologically diverse areas such as those found in Glacier are prime for monitoring environmental changes. The total community can be partitioned into trophic groups, guilds, residency status groups and individual species. Each of these groups may serve as a different type of indicator because of their varying susceptibility to changes. For example, changes in the relative contribution of guilds of species to the total community may isolate one portion of the community that serves as an indicator of a specific change (Steele et al. 1984).

Accessibility to the park is limited to two types of roads: those that skirt the perimeter of the park, and a single road that winds through the middle of the park up to Logan Pass (Going to the Sun Highway). Given these constraints, hiking is required to access many of the habitats. However, the wilderness character of Glacier makes it a prime candidate for monitoring biodiversity in an undisturbed state.

Previous inventory and monitoring programs in Glacier, as in most of the national parks, occured primarily on a species-specific basis, targeting those species of special interest. For example, grizzly bears (*Ursus arctos*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), cutthroat trout (*Salmo clarki*), and bald eagles (*Haliaeetus leucocephalus*) have been studied intensively since the inception of Glacier's science research program in 1967. Genetic analysis has been conducted on the cutthroat trout in alpine lakes. Very few taxonomic groups have been fully documented. The only exception has been through vegetation monitoring. In cooperation with the GIS, a vegetation database was created which includes geographic and topographic elements (Carl Key, pers. comm.). Further, a recent fire study incorporated the inventory of various types of beetles in its assessment (Michael Ivie, pers. comm.).

Research Goals

The goal of this research was to develop methods for replicative sampling and analysis of biodiversity in Glacier National Park, Montana. This biodiversity assessment concentrates on species diversity, but a case study of genetic diversity assessment is also included.

Some of the reasons for developing methods to inventory and monitor biodiversity in Glacier were 1) to assist in describing the current species composition, 2) to provide a method to identify diversity hotspots and rare species, and 3) to establish a technique to assess change. Ideally, these types of data will be useful in understanding the relationships between diversity and ecosystem status. However, before these relationships can be understood, one must first obtain a thorough description of the current community and the variation in baseline species distributions.

CHAPTER 2

SPECIES DIVERSITY ASSESSMENT IN GLACIER NATIONAL PARK

Introduction

One way in which the status of an ecosystem may be assessed is to document changes in its biodiversity over time. Because biodiversity can be defined at the level of species, habitats, or genes, temporal changes can be assessed at several different levels. These changes may indicate responses to natural disturbances, human-induced changes, or long-term environmental trends.

In addition to serving as a "miner's canary" for ecosystem integrity, biodiversity has important intrinsic values; thus, its protection is an appropriate endpoint in itself (Noss, 1990b). As other public lands are developed or managed for multiple-use goals, the U.S. National Park system is becoming increasingly important as a major reservoir of biodiversity in this country.

The first step in assessing the role of national parks as biodiversity reserves is development of an appropriate inventory and monitoring system for biodiversity in these parks. This chapter describes the initial steps in the development of such a system for Glacier National Park (GNP), Montana, U.S.A.

Ideally, a comprehensive inventory of biological diversity for a large, diverse ecosystem should consist of the following components: 1) accurate maps or a computerized Geographic Information System (GIS) showing all vegetation zones and habitat types, 2) accurate and up-to date species lists, distributional maps, and abundance data for all vertebrate taxa, major invertebrate taxa and plants, and 3) an assessment of genetic diversity in its rare species and species of special interest. Additionally, information on land uses (past, present, and future) and exogenous influences (e.g. acid deposition) with potential impacts on biological diversity is highly desirable. Currently, GNP has collected very little of these data.

Recognizing the importance of biodiversity to the park, Dr. Cliff Martinka, GNP's Chief Scientist, was interested in developing an inventory and monitoring program that would provide an empirically sound basis for the area's biodiversity protection. However, budgetary constraints were severe; the money available for the project was sufficient only to keep two people in the field for three summers. Could a worthwhile project be launched from such a limited resource base? Several decisions were made at the outset. First, it was clear that a comprehensive survey of habitat, species, and genetic diversity in GNP was well beyond the scope of the budget. Because a GIS-based vegetation survey with data on topographic elements, spectral classes, and fire history was already underway, and because a survey of genetic variation had recently been conducted on cutthroat trout populations, concentrating further efforts on species diversity seemed to be a logical choice. Second, it was also clear that a most useful study would have to focus on one or two taxonomic groups rather than trying to inventory the park's entire biota. Check lists of the birds, mammals, butterflies, vascular plants, carabid beetles, and spiders present in GNP already existed, so one or more of these groups was a logical possibility. The focus of this project was terrestrial, with the idea that aquatic organisms could be added at a later date. Third, a proper biodiversity assessment would necessarily be conducted on a large spatial scale--park-wide, and it would also entail obtaining information on species distribution and abundance so that clear-cut levels of commonness and rarity could be assessed. Thus, an appropriate sampling plan would be intermediate between a faunal (or floral) survey and a detailed ecological investigation. Finally, species distributions needed to be assessed because they are far easier to quantify than is abundance. Because the frequency of ocurrence of many species is correlated with their average local density (Brown, 1984; Bock, 1987), spatial and temporal trends in abundance could be estimated from distributional data--provided they were obtained in a systematic manner.

Thus, the ultimate goal was to be able to track patterns of changing distribution and abundance in several indicator taxa into the future. The immediate goals of this project were to (1) choose representative taxa that could be inventoried and monitored and serve as indices of the state of overall biological diversity in GNP, (2) establish an appropriate sampling regime and methodology, and (3) evaluate various analytical techniques for dealing with the database. Specific questions and issues regarding species diversity that were addressed in this study are noted below:

1) Describing the Data

a) What criteria should be used to select taxa for survey?

b) What is the distribution of species, communities, and ecosystems in Glacier National Park?

c) How adequate are current park species lists as historical species presence/absence documentation?

2) Species/Habitat Assemblages

a) Are predictable species assemblages routinely found in close association within a refuge? Can a given species assemblage be used to predict habitat type?

b) Is there a spatial correlation between sites of high species diversity and sites that support rare species?

c) Is there a correlation between habitat diversity and species diversity?

3) Sampling Efficiency Analysis

a) Should census sites be homogenous or heterogeneous in habitat type given a goal of identifying a maximum number of species within the limitations of personnel and time.

b) How is the cost/benefit of replication within habitat types reconciled with the need to survey a large, highly diverse ecosystem?

c) What is the most efficient use of resources? How much difference should one expect in results if the sampling effort were cut in half? If it were doubled?

d) How many samples are needed, and how intensive a sampling effort is necessary to detect rare species? How many species should one expect to miss given the effort invested?

e) How reliable are the new data collected via biodiversity inventory? What level of confidence can/should managers have in their species lists?

f) How many years of censusing are necessary to distinguish background noise from real population fluctuations? What differences should be perceived as biologically significant?

4) Management Implications

What areas of the reserve merit special protection, intervention, or efforts to manage biodiversity?

Methods

Criteria for Choice of Indicator Taxa

Diamond (1986) recommends that vertebrates should be chosen as indices of biological diversity as a whole because they tend to be the best-known taxonomically, and are politically the most easily salable. Scott et al. (1987) concur, but include butterflies as well. Because plants, fungi, and invertebrates are vastly more abundant and potentially are ecologically more significant than vertebrates, an adequate inventory and monitoring system for biological diversity should include a reasonable selection of these groups, in addition to vertebrates.

Birds are suitable because they are ecologically diverse and use a wide variety of food and other resources. Therefore, they reflect the condition of many aspects of the ecosystem. They also represent several trophic groups or guilds, and by having a short generation time, they exhibit quick responses to environmental change (Steele et al. 1984). Finally, they are good indicators because they are conspicuous, ubiquitous, intensively studied, and often appear to be more sensitive than other vertebrates (Morrison 1986).

Indicator groups need not represent any particular level of the taxonomic hierarchy; they could range from the genus level (*Drosophila*) to that of a subkingdom (vascular plants). Nor did they necessarily need to be monophyletic (e.g. "small mammals"). With this in mind, the following guidelines were used in evaluating potential indicator groups for a terrestrial environment.

1. The group must be appropriate for the park in terms of numbers of species and levels of abundance. For example, salamanders would be inappropriate because only one or two species occur in GNP in very restricted habitats. Clearly, it is much easier to establish clear-cut levels of commonness and rarity in more speciose and widely-distributed groups.

2. The group should be found throughout the park.

3. The group should be politically salable (e.g., butterflies are more appealing to the public than spiders).

4. The group must be amenable to sampling and identification to the species level by non-specialists.

5. The group should not contain species that are directly exploited by humans. The distribution and abundance of such species are likely to be influenced strongly by management practices.

6. The group should contain at least some taxa with short generation times. Such species monitored over several generations of the taxa should show rapid responses to environmental changes.

7. The group should contain species in different trophic or habitat guilds, and some of its species should respond to different aspects of the environmental matrix.

8. The group should be relatively well-known in terms of its ecology and life-history information.

Once several potential groups had been identified, the following considerations were used in assembling the overall set of groups to be included:

1) Does the set include a representative spectrum of the overall biological diversity present in the park?

2) Does it include a number of trophic levels and guilds (e.g. producers, decomposers, and various consumer guilds such as herbivores, granivores, insectivores, detritivores, etc.)?

3) Does it include groups that respond to different aspects of the environmental matrix (e.g., the diversity of bird species in most temperate zone communities is more related to the structure of the vegetation (Willson 1974), while butterfly diversity is more related to its chemical composition. Not surprisingly, Murphy and Wilcox (1986) and Wilcox et al. (1986) found that habitat components important to butterfly diversity are very different from those for bird diversity).

Groups such as (1) vascular plants, (2) macro-fungi (mushrooms, bracket fungi, etc.), (3) birds, (4) small mammals, (5) butterflies, (6) carabid beetles, (7) bumblebees, (8) drosophilids, (9) dragonflies, and (10) terrestrial molluscs satisfied most of the above criteria. Of these 10, two groups, small land birds (generally passerines plus woodpeckers and hummingbirds) and butterflies seemed particularly appropriate for the initial efforts. Both groups are tractable in the field, are taxonomically and ecologically well-known, and popular amoung amateur naturalists. Birds and butterflies also have their peak activity periods at different times of the day (early morning and mid-day, respectively) which would facilitate sampling.

Census Sites

During 1987, 84 sites were sampled. My objective in this first year was to census extensively throughout the park. Some sites were sampled for birds, some for butterflies, a few for both. These sites were selected primarily on the basis of their position in the topographic/elevational gradients in GNP instead of by habitat types. This was done for two reasons. First, temperature and moisture gradients, quite independent of habitat types defined by vegetation, are often of primary importance in determining the distribution and local abundance of most terrestrial plant and animal taxa (e.g. Whittaker 1952; Terborgh 1970; Brussard 1985). Temperature correlates with elevation, and moisture is correlated with both elevation and topography (i.e. slope, aspect, and exposure); both factors affect the metabolic functions of animals either directly or indirectly. Second, vegetation is often distributed as a continuum, so it is very difficult to divide into discreet packets, particularly at a scale that is biologically meaningful to each species in groups as diverse as birds and butterflies. Although several methods of habitat categorization were considered (Elton and Miller 1954; Southwood et al. 1979; Bunce and Shaw 1973), the technique eventually employed involved marking each site's location on a 7.5 minute United States Geological Survey (USGS) topographic map, recording its elevation, slope, and exposure, and making a brief and very general categorization of its habitat type (e.g. xeric meadow, riparian, lodgepole pine forest).

This procedure each site to be located on two-dimensional graphs representing the available "ecological space" in GNP using elevation as the ordinate and moisture conditions (ranging from hydric to xeric on the flats and based on aspect, corrected for slope and exposure, on mountainsides) as the abscissa. Additional sites were then chosen to maximize the full range of topographic/elevational conditions in the Park. Coverage by habitat type is illustrated for butterflies (Fig. 1) and for birds (Fig. 2).

The 1987 sites varied in both size and shape. Because many of them were inaccessible by road, most could be visited only once. Although this was probably not quite as serious for surveying birds due to their longer lifespan, phenological differences among butterflies (i.e., early- versus late-summer emerging species) created a potential problem for adequate coverage of this group.

In order to address the temporal replication problem, the number of sites sampled was reduced in 1988 and 1989 to 33, the maximum number that could be visited at least twice during the summer by two people. In this way, each site was surveyed more intensively, rather than surveying GNP extensively. These sites were still fairly representative of the range of geographic and environmental variation