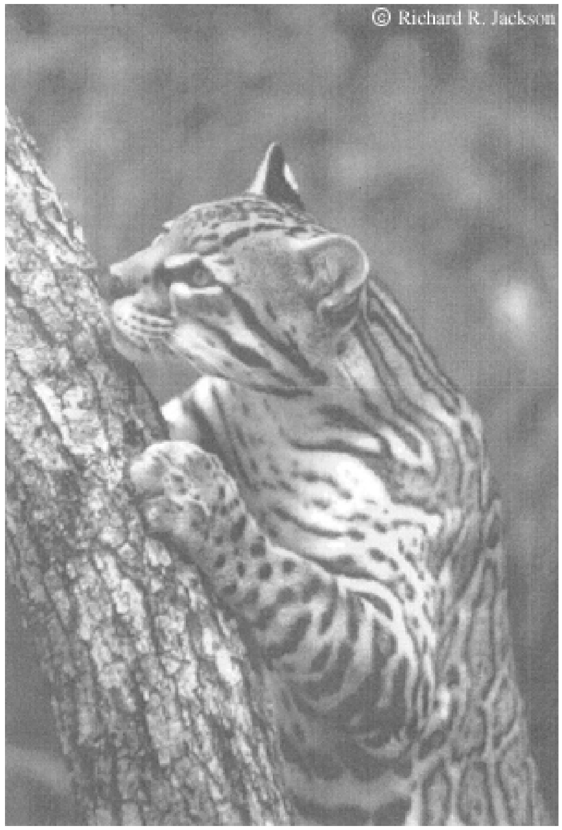
An Ecological Monitoring Program

for the

Maya Biosphere Reserve



a report to

the U.S. Agency for International Development

and

el Consejo Nacional de Areas Protegidas

de Guatemala

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EXECUTIVE SUMMARY

This document provides an initial conception of an ecological monitoring program for the Maya Biosphere Reserve (MBR). The monitoring program is presented in two parts. First, indicators related to human activities are presented, without extensive justification, as they are based mainly on common sense. The bulk of the document then develops the rationale and methods for monitoring more purely biological/ecological facets. It has been necessary to extensively develop here the conceptual basis for ecological monitoring. The document introduces the field of ecological monitoring, giving some history of the field's development, explaining the logic involved in the use of indicator suites, and discussing different kinds of monitoring and indicators. Examples are given of the successful use of indicators in various applications, and an analysis is presented of the present state of biotic monitoring in terrestrial ecosystems.

The main environmental stressors of concern in the MBR are identified, and a spatial hierarchical approach to monitoring the reserve is developed. Many potential indicators for use in the MBR are presented, the advantages of each described, and specific indicators recommended for use. Recommended sampling methods are described in detail where possible. Aspects of experimental design and data analysis are briefly discussed, and the need for further development of these facets by a professional statistician is highlighted. A possible structure is suggested for a monitoring unit within CONAP, including staff positions and responsibilities. Potential management applications of each recommended monitoring component are suggested.

The plan presented here is flexible, allowing tailoring to the interests of individuals and institutions participating in monitoring; this is desirable, as these individuals and institutions may often be required to seek funding in support of their monitoring activities. Also, where possible, simple and inexpensive monitoring methods are described as alternates for more complex and costly approaches, allowing the program to be tailored to various levels of resources.

This document hopefully will provide a strong basis for progress toward a successful monitoring plan. However, many decisions remain to be made, for example, among the indicators suggested here. Levels of funding and institutional commitment must be evaluated, and an appropriate magnitude and level of sophistication for the monitoring program selected. Substantial further development of experimental design is required, especially concerning spatial allocation of sampling, and of plans for statistical analysis.

The remainder of this executive summary consists of two tables--Tables 2 and 4. Rather than duplicate them here, they remain in the body of the text, beginning on pages 8 and 33. Table 2 presents a plan for monitoring related to human activities. Table 4 presents a plan for monitoring the biological/ecological integrity of the reserve. Note that not all the indicators proposed are deemed high priority for implementation. Also, due to limited resources, perhaps not all of those deemed high priority can be implemented. Nor will all readers will agree with the priorities assigned here; broad discussion of the relative merit of these indicators should be accomplished before the design of this program proceeds farther toward realization.

Note that a given indicator and sampling method often serves multiple purposes; indicators and methods are listed anew under each assessment endpoint, which makes the proposed program seem larger in these outlines than it really is. In total, nine assessment endpoints are proposed in that portion of the program devoted to monitoring human activities, and nine in the purely biotic monitoring portion. Multiple indicators are proposed for many of these endpoints, but it is not necessary to monitor all of these indicators. In evaluating these outlines, we suggest the reader first consider whether certain of the assessment endpoints can safely be ignored altogether, allowing concentration of resources on other threats. Then, for the threats deemed most important, one can evaluate which indicator(s) would be most informative and practical.

Most of the monitoring related to human activities does not require highly trained personnel or complicated methods. In contrast, most of the ecological/biotic monitoring requires personnel highly skilled in species identification and certain specialized field techniques. A number of peteneros already have the requisite experience for applying these methods, given adequate leadership.

Please turn to Table 2 (pp. 8-11) and Table 4 (pp. 33-35) to complete this overview.

FOREWORD

If a thing is worth doing, it is worth doing well. Nowhere is this more true than in designing an ecological monitoring program. By definition, monitoring is a many-year effort which, over time, will consume tens of thousands of person-hours and large sums of money. After such large expenditures, a poorly designed program may produce little of value. There has been a notorious tendency for monitoring programs to be poorly conceived; the monitoring literature is full of allusions to programs which at worst are characterized as mindless data gathering, and at best, fall short of the results that may have been achieved with more careful planning. Even large, nationwide programs have been placed within the ranks of the ill-conceived (Hinds 1984).

The foregoing comments should serve as a warning--there is a large danger of our creating a half-baked monitoring scheme for the Maya Biosphere Reserve, and to avoid such an outcome, we will have to adhere to the highest standards of careful planning. The largest danger is to believe that monitoring is a simplistic endeavor that can be carried out with minimal planning and on a shoestring budget. If we do not commit substantial human, institutional and financial resources to this endeavor, we heighten the risk that the resources that are committed will be wasted. Though it may be possible to carry out a limited and simplistic monitoring program with modest devotion of resources, much more of value will be created if we make a larger commitment, especially during the planning and initial execution and refinement stages, say over a three-year period.

It is important to realistically view the limited ability of this document to present a polished monitoring plan for the Maya Biosphere Reserve. The process of designing a monitoring program for the MBR should involve an in-depth, well-funded effort by a number of skilled professionals specializing in different topical areas. Such an approach is exemplified by that of EPA (the U.S. Environmental Protection Agency) in designing EMAP, the Environmental Monitoring and Assessment Program. Appendix 1 describes some aspects of the EMAP program and the design process used therein; this process clearly involved long term participation of many scientists, and no doubt cost a large sum of money.

It may have been hoped that this document would specify a monitoring plan in minute detail, ready to be employed in cookbook fashion. This was not possible or desirable for various reasons. For one thing, greater flexibility and scope for institutional and personal interests is required. Second, more individuals (and particularly CONAP leadership) need to consider the relative priorities of the various components proposed herein. Finally, funding levels and degree of commitment on the part of various participating or potentially participating institutions must be determined before final decisions as to program components can made.

Our intent here is to give this process an auspicious birth. However, readers should recognize that this document is but the first step in the process of designing and putting in place a successful monitoring program for the Maya Biosphere Reserve. It should be thoroughly reviewed by interested parties, and a committee convened to take the project to the next step, of concrete decisions between alternatives presented here. Moreover, a professional statistician should be involved as plans progress, to help guarantee an efficient, powerful experimental design. We should view this task as an opportunity to break important new ground in conservation--possibly, a comprehensive ecological monitoring program functioning in the MBR would be a worldwide first for any large, tropical forest protected area.

I beg the reader's indulgence for my use of the pronoun "we" throughout this document. I have written it single-handedly, but such extensive use of the first-person singular was offensive to me. Hence, I use "we" in offering this as a Peregrine Fund product. Finally, I beg pardon for the length of this document; I am aware that it would profit from further editing. To paraphrase Mark Twain, I didn't have time to make it shorter.

1. INTRODUCTION

1.1 ANTECEDENTS

In 1995, USAID/Guatemala requested that The Peregrine Fund, in consultation with CONAP, create a plan for biological monitoring of the Maya Biosphere Reserve in Petén, Guatemala. Beginning in November 1995, we have attempted to gather input from the widest group possible of those working on conservation issues in the Maya Biosphere Reserve (MBR). At that time, we distributed a brief outline of a proposed monitoring scheme at a meeting in Chetumal, Quintana Roo, on Conservation and Community Development in the Maya Forest, soliciting suggestions; several were received. In May 1996, we produced a 35-page first draft of a monitoring plan, in both Spanish and English versions. This was distributed widely among those active in conservation and research in the MBR, soliciting critique, which was received from several colleagues. To facilitate more direct participation, we held a meeting (with assistance of ProPetén) in Flores, Petén on 7 October 1996, which was attended by 18 persons representing at least eight institutions. Discussion was animated and many useful suggestions were produced. In arriving at this final draft, we have considered all the comments received, and wish to thank those who took time to comment.

1.2 SCOPE AND GOALS OF THE DOCUMENT

Recommendations for inventory and research

While our mission was defined as designing a "biological monitoring plan" for the MBR, we soon realized that different parties imbue the word "monitoring" with different meanings. This left our task poorly defined. Moreover, as we grappled with this task, we came to see that CONAP, our main client, desired information beyond that provided by a pure monitoring program as conceived by us. We met several times with CONAP personnel to discuss that agency's needs with respect to biological information in support of reserve management. It became clear that CONAP, while interested in biological monitoring, also desired information to help answer questions such as the following: 1) What are the biological resources of the Maya Biosphere Reserve and where are they?, 2) Are there ecologically unique sites that merit special protection? 3) How are the reserve's natural communities affected by various land uses? 4) Where should corridors between core zones be located? These are all questions best answered by biological *inventory* and *research* rather than by *monitoring per se*. Hence, while our main goal is to present a monitoring plan, we also comment on ways in which biological inventory and research can help improve management and protection of the reserve.

Development of a monitoring plan

The chief goal of this document is to present a plan for monitoring the biological integrity of the Maya Biosphere Reserve. Our objectives are the following: (1) to provide a thorough conceptual basis for ecological monitoring in general; (2) to identify the principal stressors important in the MBR, and specific kinds of monitoring needed; (3) to suggest relevant "assessment endpoints", i.e., the environmental values which we are ultimately concerned with safeguarding; (4) to specify indicators that will serve to monitor these values; (5) to the extent possible, describe methods for sampling these indicators; (6) discuss some aspects of experimental design, data analysis, and various practical issues, (7) suggest a personnel and organizational structure for a monitoring unit within CONAP, and (8) discuss such other issues as appear relevant to the design and conduct of ecological monitoring of the MBR.

A flexible prescription for monitoring

The prescription for monitoring presented here is flexible, for several reasons. First, any comprehensive monitoring plan for the MBR will of necessity be carried out by a variety of individuals and institutions with differing interests and priorities. These participating entities may often be required to raise some or all of their own funding in support of monitoring efforts; hence it is not realistic to think that they will willingly carry out a mandated list of tasks which may depart from their special interests. Nor is it truthful to present a list of indicators as if they were the only ones useful for monitoring in the MBR; many indicators are possible. Moreover, there are more endpoints and indicators worthy of monitoring than are likely to be employed, due to limited resources. All of these factors leave scope for choice among assessment endpoints and indicators. Thus, rather than giving a rigid prescription for monitoring, we present a prioritized set of desirable components, which hopefully may find common ground with the interests of groups and individuals likely to play roles in monitoring of the MBR.

Still, we have strived to discuss important aspects of program design that should be adhered to by all participants, and to provide detailed methods for those components we consider especially high priority.

A further reason for flexibility is that little certainty exists as to what level of commitment or sophistication will be possible in a monitoring program for the MBR. While it is obviously desirable to have as sophisticated a monitoring program as possible, this implies a need for highly trained personnel and high funding levels. Though we don't rule out this possibility, it is perhaps more likely that only a more modest effort will be possible. To meet both needs, and in compliance with our contract with AID, throughout this plan we present options ranging from an ideal scenario, often requiring sophisticated methods, highly trained personnel, and substantial funding, to a more basic option, largely achievable through the efforts of resource guards and other personnel already in place, and with minimal equipment, funding and training. Which of these are realized can then be adjusted to existing constraints of funding and other resources.

The biggest unknown is whether there will indeed be a comprehensive monitoring program at all. We do not see any sense in attempting such a coherent program unless there are permanent staff in place in some institution (presumably CONAP), who are in a position to manage, analyze, and use the resulting data. Appendix 19 suggests a potential structure and functional roles for such a unit within CONAP.

Potential contribution of the MBR to global monitoring efforts

The MBR could potentially make a great contribution toward monitoring global environmental change. Because of its large area of near-pristine habitat, the MBR could serve as a crucial laboratory for ecological research under near-pristine conditions, aiding us in understanding global changes underway now or in the future. In this document, we try to give some idea of these potential roles for the MBR. However, a far more modest monitoring effort is likely to see fruition in the MBR, unless substantial involvement by a variety of sophisticated collaborators is solicited. While instituting at least the minimum program recommended here, we should strive to maximize the level of monitoring and research within the MBR, by soliciting involvement of outside collaborators.

1.3 GOALS OF MANAGEMENT OF THE MBR

The goal of management of the Maya Biosphere Reserve (MBR) is to guarantee the conservation of the reserve's ecosystems and natural resources as well as the sustainable use of the same for human welfare. We interpret this broad goal to include the following objective--to maintain the full native biota of the MBR, within the natural range of values of species abundance, genetic diversity, and rates and patterns of ecological, ecosystem and landscape processes--over a time span of several centuries, while also providing sustained benefits to humans. An additional goal is to foster sustainable lifestyles of people living in and near the reserve. In turn, the primary goal of monitoring is to aid in the achievement of these management goals.

1.4 DEFINITIONS

Much confusion exists over the differences between ecological *inventory*, *research*, *monitoring*, and ecological *evaluation* and *assessment*. Here we define the sense in which we use these terms. *Biotic inventory* is the gathering of data that quantify and describe the biota of a given area, answering the question "What is out there, how much, and where?" It may be carried out at the level of the gene, individual, population, species, community, habitat, ecosystem, or landscape, but here we consider levels from the population upward. When inventory is conducted in a systematic fashion and repeated at a later date, this can yield *monitoring*. Inventory can also be conducted in such a way as to achieve research objectives (e.g., allowing comparisons between sites or habitats).

Ecological (= biological, biotic) monitoring is periodic (regular or irregular) surveillance over the biota or related properties (e.g., ecological processes) in a way which facilitates detection of significant changes from predetermined standards or norms, allowing corrective actions. By way of contrast, *research* usually endeavors to discover a general relationship, often of cause and effect. Research most often seeks to establish generalities that allow extrapolation and prediction to other times, places, and circumstances. In contrast, inventory and monitoring involve documenting specific instances. Though both monitoring and research should require the same degree of scientific rigor, the requirements for replication may vary, depending on the breadth of the "universe" to which one hopes to extrapolate results. In neither case can one extrapolate beyond the universe of situations justified by the diversity of situations in which one has studied the entity in question. In monitoring, one must be very clear about what universe is in fact being monitored. If, for example, one monitors birds only at Tikal, one can scarcely claim to be adequately monitoring bird populations of the entire Maya Biosphere Reserve; to achieve the latter would require sampling throughout many portions of the reserve. In research, one is normally only predicting that a certain relationship or tendency will hold true within a stated universe, rather than claiming to know the *continuing status* of a quantity throughout this stated universe. Hence in a manner at least, to adequately monitor an ecological quantity can be at least as demanding as are many ecological research projects.

In the MBR, there has been much discussion of "monitoring" the effects of certain land uses, in particular, selective logging. Here there is a great need for clarity. If one hopes to make general statements about the way in which some component of the biota responds to logging *in general* (a type of land-use practice) this entails *research* and requires replication, that is, study of more than one logging operation. If one is interested in the effects of a *specific* logging project (a land-use *project* rather than a practice in general), this involves *monitoring* or, perhaps more appropriately, "*impact assessment*", and requires adequate documentation of that particular logging operation (and of adequate control sites).

Other related concepts are those of ecological *evaluation*, *assessment*, and *conservation prioritization*. Evaluation and assessment are synonymous. These terms refer to the characterization of some ecological unit with respect to some criteria which provide values against which the unit is judged--degree of "naturalness", "representativeness", etc. These terms refer only to an approach or process, and do not have any particular meaning at all in the absence of a clear statement of the set of standards or values employed therein. Conservation prioritization is an area of much activity, and is the act of using criteria in order to set priorities for land acquisition or other conservation actions. Many criteria have been used for prioritization.

We wish to emphasize that this document does not concern itself with "project M and E", i.e., monitoring and evaluation of *projects*, including those that comprise USAID's Maya Biosphere Project. Though some of what is presented here could no doubt be adapted to the purpose of project monitoring and evaluation, such an undertaking has a fundamentally different goal than that of monitoring conservation status and ecological integrity of the Maya Biosphere Reserve.

1.5 WHY CONDUCT ECOLOGICAL INVENTORY, MONITORING, AND RESEARCH IN THE MBR?

Table 1 lists some of the kinds of scientific information needed for management of the MBR. Biotic inventory is most needed during the initial phases of reserve creation--in providing rationale for the size, location, and internal zonation. Evaluation and assessment are also needed at an early stage in order to define natural lines at which the reserve may be defended against encroachment, as well as sites where guard posts and other infrastructure should be placed. Research is needed initially to inform all aspects of reserve design and aid in setting policy such as permissible land uses. In many cases published research conducted elsewhere provides general principals which are relevant for reserve design. There is a continuing need for research in order to fine-tune management policy, and perhaps reserve design, in light of local conditions.

Table 1. Kinds of information needed for management of the Maya Biosphere Reserve.

Management Challenge	Type of information needed	Design/methods facilitating collection of such information
Reserve zoning	What is "out there" and where? (especially, unique or ecologically very important areas; also rare and endangered spp)	1. airphoto/remote sensing, veg. mapping 2. "rapid assessment" 3. inventory in many areas *(all are forms of inventory)*
Regulations governing hunting and non-timber forest product industries	1. What is size, trend of population? (census data, demographic data [age structure, reproduction, survival]) 2. How do populations of the species respond to hunting/harvesting pressure? (i.e., different intensities, timing and frequency of harvest)	1. Censusing of density or rel. abundance, along transects from areas of high extraction intensity to areas of low or zero extraction, but in similar habitat (eg, from village to core of nuclear zone or wild area) *(monitoring)* 2. age structure, demographic data (from hunter bags or plant demography studies) *(monitoring)* 3. response to harvesting *(research)*
Track overall conservation success and ecological "health" of reserve, including success of management.	What are temporal trends in indicators of biotic integrity and conservation success?	Repeated sampling via repeatable methods. *(monitoring)*
Setting land-use and reserve management policy	What land uses are compatible (in general) with reserve management objectives?	1. BACI (Before-after-control-impact) design 2. "Horizontal" comparison--e.g. guamil compared to mature forest; logged vs unlogged. *(research)*
Evaluating land-use and reserve management policy, monitoring compliance	Are land uses being conducted in a sustainable and ecologically acceptable fashion in specific instances?	1. BACI design *(monitoring or impact assessment)*
Allocation of infrastructure and human resources for protection and vigilance	Where should guardposts be? What patrol routes should be used?	*Evaluation* and *assessment* of natural lines of defense, access routes, etc.

The main reason to conduct ecological monitoring in the MBR is to help ensure that conservation goals of the reserve are achieved. Monitoring is needed in order to reveal whether reserve management is effective, and to specify ways in which management policy or reserve design need to be altered in order to achieve conservation goals. In short, monitoring reveals whether the reserve is "working". Without adequate monitoring, reserve managers must proceed in an information vacuum, merely assuming that conservation objectives are being achieved. Experience and a large body of theory demonstrate that conservation goals are *not* necessarily achieved within reserves; hence, monitoring is essential. Monitoring takes on special importance when biotic elements of the reserve are subject to direct, exploitative human use, as are populations of hunted animals, timber trees, and non-timber plant species of the Maya Biosphere Reserve. Such monitoring, aimed at evaluating adequacy of management, is sometimes termed *impact* monitoring.

An additional goal of monitoring is to reveal tendencies within the biota, apart from the effects of reserve management. For example, monitoring can help reveal effects of regional or global changes that affect attainment of conservation objectives, apart from the impact of local management practices. While a management response may or may not be possible to such "macro" trends, it is highly worthwhile to be cognizant of their existence and manifestations within the reserve. Such monitoring of the general status of the biota, irrespective of management practices, is sometimes termed *baseline* monitoring.

Another reason to conduct biotic monitoring is to meet legal obligations. Article 7 of the United Nations Convention on Environment and Development requires signatory nations (of which Guatemala is one) to "identify components of biodiversity important for conservation and sustainable use…and monitor, through sampling and other techniques, the components of biological diversity identified." The convention also calls for signatories to "identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects" (Stork and Samways 1996). A final reason to conduct monitoring is to verify compliance with relevant regulations and management plans; though not a primary focus of this document, the need for such *compliance* monitoring is highlighted in a few cases.

Monitoring motivated by any of the four reasons given above contributes to the ultimate goal of securing the long-term benefits for humankind provided by the reserve. In this document we focus on detecting the kinds of changes that signify impending loss of ecosystem integrity, and that can be reversed, halted, or mitigated by actions or policies in and near the MBR. Changes best addressed globally (e.g., climate change) are also considered, but given less emphasis.

2. MONITORING HUMAN ACTIVITIES

Approaches to monitoring the effects of human activities on the biota of the MBR may be grouped into two broad approaches--that of monitoring the effects on the biota, and that of monitoring the magnitude and characteristics of the human endeavors (from which probable effects on the biota, and other assessment endpoints, can be estimated). In this section we present those aspects of a potential monitoring program that focus on the human endeavors themselves. The components proposed in this section do not, we feel, require extensive justification or explanation, and are largely dictated by common sense. Components which are more purely biological and ecological in nature are presented in a later section.

Table 2. Monitoring human activities--proposed assessment endpoints, indicators, sampling methods, and priorities.

Threat/stressor/assessment endpoint to be monitored	Indicator	Sampling/data collection method	Priority
1. Deforestation, forest fragmentation	* measures of cover change	* remote sensing, GIS, cover change detection methods	highest
(rate, localities)	* measures of fragmentation and connectivity	* Fragstats, other programs measuring connectivity	low
		* visual inspection of cover change image	high

2. Penetration of new access into erstwhile pristine areas	* road construction and improvement	* resource guards document on ground; map with GPS * infer from satellite imagery; ground-truth	high high
3. Human population tendencies	* size, age structure of population * source of immigrants, reasons for immigrating	* municipalities conduct biennial census * NGO's maintain annual estimates for areas of responsibility * census of focal villages every 3 yrs as part of lifestyle sustainability survey	high high high
4. Livestock industry tendencies	* area of pasture * number of cattle	* track pasture area via satellite imagery * count cattle entering reserve * resource guards gather data during patrol * periodic lifestyle sustainability survey	high low high high
5. Sustainability of lifestyles of MBR residents	* questionnaire/interview responses	* periodic lifestyle sustainability surveys of focal villages	high
6. Non-timber forest product industries: sustainability			
A. Performance aspects of industry	* size, value of harvest, by area * quality of harvest, by area * harvest per unit effort * distribution of monetary benefits	* Chicle - harvest reports accompanying each shipment from camps; xate - report form filled out with each sale from xatero to intermediary. * chicle - purity, % moisture (CONAP, SUCHILMA testing); xate - number and % of leaves rejected during selection * chicle - harvest reports (see above); xate - data sheets filled out with each sale from xatero to intermediary. * chicle - data routinely reported; xate - require report to CONAP of each sale (quantity and price) at each stage	high high high low

B. Plant populations:			
Chicle	* demography of chicozapote population (size distribution; survival and growth rate per size class; regeneration rate; fruiting rate)	* various sampling methods, plotless and plot-based; based partly on marked trees	high
	* response to different tapping frequencies (survival, growth, fruiting, latex yield)	* longterm experimental study as part of regular, for-profit extraction in community concessions; marked trees	high
Xate	* demography of main xate species; density, rates of flowering, fruit production, establishment, growth and survival	* plotless and plot-based sampling methods, partly using marked plants	high
	* response to different intensities, frequencies of harvest; same indicators as above	* experimental trials at various extraction intensities, frequencies	high
7. Commercial logging			
A. Industry performance, compliance	* amount and source of wood leaving reserve, by species and size class	* stringent inspection of wood shipments at control stations; verification of veracity of "guías"	high
		* concessionaires provide annual report	high
		* exert quality control over the reporting process which exists	high
	* value and tax revenue of wood leaving reserve	* concessionaires provide annual report	low
		* CONAP gather tax data from relevant gov't agency annually	med
B. Plant populations (mainly caoba, cedro)	* standing crop density, size structure of population	* concessionaires carry out ongoing studies, using approved methods	high
	* regeneration rate		high
	* rates of growth and survival per size class, especially juvenile classes	* concessionaires maintain forest inventory of specified sampling intensity and design; update annually with new demographic	high

		and harvest data * use the above to predictively model future forest resources of concession and modify cutting regime and other mgmnt practices	
8. Trafficking in psittacines	* magnitude of trafficking, especially of macaws	* CONAP confiscation records * data from vigilance at Flores airport * data from guard posts and resource guard patrol	high
9. Subsistence Hunting		* base all of the following on detailed work with focal hunter groups in selected villages, on rotating basis:	
	* harvest per unit hunting effort	* hunter data recorded for each hunting session; method, effort, bag	high
	* demographic traits of harvested animals	* preserve and inspect relevant parts; determine age, sex, repro condition	med
	* hunter impressions of population tendencies of game species	* interview	high

Proposed Indicators and Sampling Methods

Following the sequence of Table 2, our recommendations are as follows. Where we do not give separate headings for preferred and alternate methods, the methods presented are the simplest and lowest cost methods we could envision.

2.1 Monitor change in vegetative cover

Monitoring of change in vegetative cover is the most important single monitoring task that must be carried out in the MBR. This monitoring needs to document both overall rates and the specific locality and local rates of vegetative change. The most important topic for monitoring is the rate of deforestation (removal or drastic alteration of primary forest). In addition, monitoring of the destruction or modification of other natural vegetation types (e.g., wetlands, natural savannas) is desirable, and will become increasingly important as invasion begins to affect these habitats more. To the extent practical, it is also desirable to track subsequent land uses and cover types after initial forest clearing.

A secondary goal may be that of documenting rates, localities, and extent of forest modification by processes such as selective logging and fuelwood cutting which lead to alteration rather than deforestation. However, we suspect this is much more difficult to achieve via remote sensing, and regard it as a lower priority than the task outlined above. A tertiary goal is to document degree and pattern of habitat fragmentation and analyze probable effects on biological connectivity. Indices of fragmentation and other spatial characteristics may be investigated through the satellite-based cover change images referred to above, in conjunction with GIS and computer programs such as "Fragstats" (McGarigal and Marks 1994) and that of Schumaker (1996). Finally, attention could also be paid, especially as fragmentation progresses, to adjacency and connectivity patterns between the different habitats and topographic regions which comprise the total landscape pattern of the MBR--i.e., "landscape integrity" could be monitored.

Preferred methods:

Cover change analysis is best achieved through satellite imagery, image analysis, and GIS, with ground-truthing as needed, as it is currently being conducted, mainly by Dr. Steve Sader of the University of Maine, in collaboration with NASA and Conservation International. We recommend this analysis be repeated for the entire reserve at intervals no greater than two years. Methods for subsidiary goals are mentioned above.

Low-tech/low cost alternative:

There is no low-tech alternative that gives results comparable to those of the preferred approach. In the event that the preferred approach becomes impossible for some reason, the option of secondary preference would be to conduct periodic aerial reconnaissance and photography, especially in areas known or suspected to be subject to high rates of deforestation. If this too were impossible, the only recourse would be to gather information by direct observation on the ground, for example, during patrol activities by resource guards. However, the latter approach is infinitely inferior to use of satellite imagery. If funding for monitoring is limited, the remote sensing component should form the core program which receives whatever funding is available. In addition to the satellite-based approach, resource guards should routinely record information on deforestation activities during patrol activities, using a standardized report format (e.g., Appendix 7).

Some specific topics for monitoring and research:

1. Conduct a detailed study of the subsequent history of sites whose initial deforestation is documented via satellite data. Determine how often sites are refarmed, how many are converted to pasture, and how many turn into degraded wasteland such as "talquizal" and "chispal" (*Pteridium aquilinum* monoculture).

2. Study patterns of ownership in relation to deforestation and subsequent patterns of land use. How many landowners are responsible for how much of the deforestation? What are their motivations for deforesting? How does security of land tenure affect deforestation dynamics?

3. Biotic communities that are of limited occurrence in the MBR may merit special attention.

2.2 Monitor road construction and improvement

Sader et al. (1996) have shown that more than 90 % of recent deforestation within the MBR has taken place within 2 km of roads; obviously, construction and improvement of roads into erstwhile inaccessible areas facilitates invasion and deforestation of the reserve. For this reason, efforts should be made to monitor road-building and improvement, including logging roads to the extent possible.

Preferred methods:

The preferred method in this case is the low-tech method. Information on creation of new roads and improvement of existing roads should be routinely gathered during patrol activities by resource guards, who should map out new roads using GPS. This method has higher resolution than that of satellite imagery, and will allow more rapid detection of new activities and hence more timely response than would be possible through periodic analysis of satellite images. Nonetheless, satellite imagery and change detection should also be used to infer existence of roads from deforestation patterns. Resource guards should then be sent to verify or falsify the postulated existence of roads in the areas thus highlighted, and to map them.

2.3 Monitor human population tendencies in the reserve

To best manage the reserve, CONAP no doubt can benefit from information on the number of people residing in the reserve, and on the way in which they use the natural resources therein. Information on resource use is provided under another indicator; here we address the question of the number and distribution of people. Ideally, one would monitor the size and growth rate of the human population, by management unit. It is difficult, however, to know which of the following methods is most realistic and practical.

a. Size and age structure of population

Preferred methods:

Ideally, a complete census of the reserve would be achieved every two years, via door-to-door interview. This might be achieved in various ways.

1. Possibly the most practical plan is for each NGO to census the portion of the reserve for which it has responsibility; in areas where no NGO has responsibility, CONAP would have resource guards conduct the census.

2. Alternatively, CONAP resource guards could conduct the census, aided by NGO's as appropriate.

3. A third possibility would be for municipalities to conduct the census. However, this would require adequate incentive to make this task attractive to municipalities; perhaps a fiscal incentive could be arranged.

4. A fourth approach would be to periodically award a small contract to an NGO for the purpose of conducting a reserve-wide census.

5. Regardless of the above efforts, resource guards, during patrol activities, should make frequent estimates of population size along their patrol routes, in particular noting new dwellings and family units.

6. During the course of periodic surveys of lifestyle sustainability (see below), census data should be collected on focal villages.

Low-tech, low-cost alternatives and ancillary data sources:

1. Take advantage of population data gathered annually by SNEM, the national malaria control agency. However, SNEM data are believed to systematically undercount the population (N. Schwartz, pers. comm.); hence a correction factor would be necessary. Initial studies could determine whether accurate population estimates may be possible by use of an adjustment factor to predict true population from SNEM data. If so, such a factor could be applied to annual SNEM data to estimate annual population within the MBR. However, we question the advisability of this approach; its accuracy would have to be independently verified for a couple years before being considered trustworthy.

2. Collect data on immigration at CONAP control posts at entries to the reserve. This does not appear practical because control posts do not exist at all reserve entries, and existing posts are not always in operation. Furthermore, where control posts are in operation, people may not freely provide such information.

3. Periodically gather data from INTA, FONAPAZ, ACNUR, SEGEPLAN, NGO's, Municipalities, and any other agencies that work with reserve occupants, regarding population size and changes in the areas where they work. Use these data to update and adjust population estimates by management area.

4. When national censuses are conducted, every effort should be made to guarantee accuracy of results obtained within the MBR. (The most recent federal census is widely regarded as having badly underestimated populations in northern Peten). These results should then be used, if appropriate, to correct estimates resulting from other data sources.

5. Satellite imagery should be used to discover areas of current immigration, to point out areas where census data need to be gathered.

b. Sources and causes of immigration to the reserve

It is important to learn what geographical regions are the sources of continuing immigration to the MRB, as well as the causal factors that prompt these people to leave their areas of prior residence and to immigrate to the MBR. Such information would allow evaluation of possible ways to address such emigration at its geographical sources, and in its true causes.

Preferred methods:

Is is perhaps preferable that some entity other than CONAP take responsibility for such monitoring; in this case, CONAP should regularly solicit results from that agency. However, this kind of information should also be gathered as part of the lifestyle sustainability surveys described elsewhere here. Moreover, CONAP may need to acquire such information in specific instances, in areas of active immigration as delineated by satellite images and other sources.

2.4 Monitor extent of livestock industry in the reserve

Preferred methods:

1. Ultimately we are concerned with the area of cattle pasture within the reserve, and the rate of its expansion, rather than with the number of cattle involved. Hence it is important for satellite cover change detection efforts to estimate the extent of pastures in the MBR, and the rate and locality of their expansion. This should be a routine part of satellite-based efforts, and should include adequate ground-truthing to verify whether areas thought to be pasture are indeed devoted to cattle-ranching.

Low-tech, low-cost alternatives:

1. Additionally, or in lieu of remote-sensing efforts, one could monitor the number and type of livestock within the reserve, by area and management zone, as well as those entering and leaving the reserve. To an extent, this could be achieved through an initial livestock census, followed by comprehensive recording of livestock entering and leaving the reserve, by personnel at control posts at reserve entry points.

a. At entry posts, resource guards could collect data on the number and kind of livestock entering and leaving the reserve, and possibly also their source and destination.

b. Resource guards should collect information, by direct observation during patrol activities, on areas of livestock ranching, number of livestock, and pasture expansion.

c. Periodic census via interviews throughout the reserve (see section on "monitoring sustainability of lifestyles of MBR residents")

More than one respondent who critiqued earlier drafts of this plan commented that gathering data at CONAP guard stations is not feasible, for the following reasons: (1) It is easy to circumvent guard stations, (2) people may not freely provide information to CONAP personnel, and (3) attempts to collect information may endanger CONAP personnel or prevent CONAP from establishing rapport with reserve residents. We tend to agree that this approach is probably not nearly as useful as the remote-sensing approach. However, we feel that to shrink from collecting information at control posts for such reasons is unjustifiable. If data are collected simply on the number of animals entering or leaving, and no inquiry is made as to source or destination, this would be unobtrusive and non-threatening. The larger problem is perhaps that guard stations are unmanned, sporadically manned, and perhaps not in existence at all access points to the reserve. In sum, we do not feel that taking data at guard posts holds much promise; the remote sensing approach, coupled with ground-truthing, observation during patrol, and lifestyle interviews, is much superior.

2.5 Monitor sustainability of lifestyles of reserve residents

It is important to monitor the ways in which residents of the MBR sustain themselves and interact with natural resources of the reserve. To achieve management goals of the MBR, reserve residents and others who use the reserve should progressively move toward economic activities that utilize the natural resources of the reserve in a sustainable fashion, guaranteeing a steady flow of human benefits from the reserve over the long term. Monitoring the nature of household economic activities will help indicate whether this goal is being met.

Preferred methods:

These data are best collected through periodic questionnaires conducted from door to door in focal localities. Detailed questionnaires should be developed, tested, and refined. These should be employed in focal villages throughout the reserve, with each village resampled periodically, perhaps every three years. Questionnaires should be devised so as to reveal what percent of household sustenance stems from different sources, considering not only cash income, but also crops grown for family consumption and the importance of hunting, fishing, and other extractive activities. Data should also be collected on levels of health and education of family members. Additionally, this is a primary way to measure the efficacy of NGO efforts to promote more sustainable lifestyles in reserve residents. Data collected should include ample coverage of agricultural practices and trends--kinds and acreage of crops grown, length of fallow periods, amount and age of guamil cut, amount of primary forest cut, use of frijol abono, number and kind of domestic animals, and use of chemical fertilizers and biocides.

Villages recommended for use as focal villages include Uaxactún, Carmelita, San Miguel la Palotada, La Pasadita, Cruce a Dos Aguadas, Bethel, El Naranjo, 3-6 sites between La Libertad and El Naranjo, and 2-4 sites along the road from Ixlú to Melchor de Mencos. Additional villages should be incorporated as appropriate, especially in areas of intense immigration to the reserve. Census efforts should be alternated so that three to six villages are surveyed each year, with each village repeated every three years.

2.6 Monitor sustainability of non-timber forest product industries

It is important to monitor the vitality and sustainability of the xate and chicle industries; some effort could also be dedicated to the pimienta industry, but this would seem a lower priority due to its smaller magnitude. Two distinct kinds of monitoring are needed: 1) monitoring of various performance aspects of the industry (harvest per unit effort, etc.), and 2) monitoring of the demography and productivity of the relevant plant populations. For chicle, xate hembra, and jade, we recommend that the following be monitored.

Monitoring performance aspects of the industries--preferred methods:

1. Total amount harvested, and amount harvested per unit search/harvest effort, by area.

To some extent, harvest data are already gathered by CONAP; efforts should be made to ensure that such data are complete and accurate, overall and by area and management unit. However, data on amount harvested is not very revealing unless the amount of search and harvest effort is also specified. For example, xate harvests could go up because additional areas are harvested, even while return per unit of search effort declines due to degradation of the resource. Hence, it is crucial to document the amount of search and collection effort expended in generating a given amount of harvest. Those involved in each non-timber forest product industry must decide the best way to quantify search effort and to collect such information. Tentatively, we recommend the following:

A. Chicle - All shipments of chicle from forest camps should be accompanied by a statement of: (a) total harvest and total number of chicleros and chiclero-days involved in generating it, (b) quantity (mass) of chicle collected by each chiclero, and (c) number of days spent by each chiclero in collecting that amount. The two latter numbers should be clearly stated per individual, so that chicle harvest per unit effort may be calculated for each chiclero. Shipments of chicle from the forest should clearly specify the camp of origin and describe the boundaries of the area for which harvest is reported.

B. Xate - A form should be developed, which contratistas and rural collectors would be required to use in recording each purchase of xate from a xatero. The form would be filled out at the time of each such transaction, and would report: a) locality where sale transaction takes place (this would indicate roughly the area of extraction) b) number of gruesas (and numeric definition of a gruesa) per species of xate, and c) amount of harvesting effort entailed (hours or portions of a day), and d) sale price paid to the xatero. These forms should be turned in to CONAP at frequent intervals (monthly or quarterly). This simple expedient would largely provide the information currently lacking on harvest per management area and on harvest rates per unit search effort.

C. Pimienta - We do not currently see a critical need for monitoring of the pimienta industry. However, if such a need is deemed to exist, the approach described above for xate could be employed.

2. Quality harvested, by area and management zone.

It is important to gather data on quality, especially for xate, as this is a highly variable factor which influences harvesting pressure. As much as half of the xate leaves harvested are discarded during sorting, due to their being undersize, imperfect, or damaged.

a. Chicle - Gather data on purity and percent moisture; these data are already routinely gathered by CONAP and/or SUCHILMA.

b. Xate, jade - Gather data on number and percent of leaves rejected during the selection process due to small size and poor condition, by area and management unit.

3. Monitor distribution of monetary benefits within the industries and tax value to the nation.

Data on export and tax value to the nation is useful, enabling CONAP to demonstrate the economic contribution of these reserve uses to the nation, and in balancing land use between conflicting demands. Moreover, data on the distribution of benefits within these industries are important, as these factors influence intensity of harvest pressure on plant populations.

a. Chicle - Distribution of benefits within the chicle industry is fixed by law. Nonetheless, it is worthwhile to monitor the amount earned per chiclero per season, as well as by contratistas and others involved in the industry, as a measure of the ability of the chicle industry to contribute effectively toward sustaining families in the MBR. Hence, CONAP should analyze and report on these data each season. SUCHILMA should play as large a role as possible in assembling these data, in order to remove some bureaucratic burden from CONAP.

b. Xate - Real wages paid to xateros have declined as costs of living have increased. This decline in real wage has promoted overharvest, as xateros must harvest progressively more product in order to make a given amount of money. Hence it is important to monitor the wage per gruesa (along with the definition of a gruesa) and the wage per unit collection effort (see above), experienced by xateros. This should provide a partial indication of the economic viability of the industry and allow prediction of tendencies in harvest intensity. The reporting procedure described under point 1 above will provide the necessary information on the amount paid per purchase by middlemen and on amount of search effort, allowing calculation of economic return to xateros per unit search effort.

Realization of monitoring goals - Apparently plans are underway that will fulfill at least in part the needs identified above. *ProPetén* is well along in the process of creating a map of all or most of the xate and chicle camps existing in the central portion of the MUZ. From this list, ProPetén will select a subset of camps that will be visited to collect more detailed data.

Monitoring demographic indicators for xate, chicle and pimienta

Existing data indicate that in many cases, non-timber forest products are exploited at unsustainable rates (Hall and Bawa 1993), and there is evidence that this is true for both xate and chicle in the Maya Biosphere Reserve (Heinzman and Reining 1990, Dugelby 1995). Moreover, such industries may remain *economically* "sustainable" (i.e., the value of the industry, adjusted for inflation, increases or remains constant), even when they are not *ecologically* sustainable (Hall and Bawa 1993). For example, persistent demand may lead to stable or increasing total value of the harvest, even as overharvesting reduces the ecological viability of the plant resource. Hence the indicators proposed above for various performance aspects of the xate and chicle industries will probably not be adequate to monitor ecological sustainability of these industries. To monitor the latter, it is necessary to directly examine the demography of the plant populations that form the basis of these industries. This is important in evaluating the adequacy of existing management and regulation of these industries and in suggesting needed improvements.

Preferred methods:

The only truly adequate way to evaluate the impact of extraction on the demography of chicozapote and xate species, is through an experimental approach. That is, demography of exploited populations must be compared to demography of one or more unexploited ("control") populations. Ideally, one would test the response of xate and chicle to an array of extraction intensities and frequencies. Alternatively, one may compare demography of populations subjected to current "market" levels of extraction, to that of control populations. A significant problem may be that of identifying even a single population that can serve as a truly unexploited control. Perhaps the best that can be achieved is use of populations that are exploited far less than average, e.g., populations near the heart of Tikal National Park or other well-protected sites. Such studies must employ marked individual plants at least in part, and should measure rates of seedling establishment as well as size/age structure, and rates of growth and survival by size/age class. Measures of fruiting frequency and seed production may also be important, especially for xate. Suggested design features for such studies are discussed by Hall and Bawa (1993). The methods described above, though not requiring any extraordinary technology, require rigorous experimental design and data analysis by a trained statistician, and careful execution in the field. There is no adequate, simpler alternative.

Realization of monitoring goals.--Apparently plans are underway which should take care at least partly of the needs identified above. *ProPetén* is setting up a program to examine effects of harvest intensity on life histories of xate and chicle at Carmelita. Apparently *CATIE* is contemplating conducting a study of chicle yields in Uaxactún, though we have no details of this planned effort.

2.7 Monitor trends within the commercial logging industry

Two broad types of monitoring are needed within the logging industry: 1) monitoring of various aspects of the industry that help indicate its sustainability, and 2) monitoring of the demography and growth rates of the relevant plant populations. In addition, compliance monitoring, though not a central focus of this document, is badly needed.

Monitoring performance of the timber industry

Preferred methods:

1. Monitor quantity and source of wood leaving the reserve.

According to common knowledge, the amount of timber (mainly caoba and cedro) harvested in the MBR is chronically and substantially under-reported. This being the case, official harvest data are currently of little value in helping to manage the timber resource. Hence, every effort should be made to upgrade the quality of reporting on timber harvested from the MBR. The most basic requirement is to adequately monitor the amount and geographic origin of all wood shipped out of the reserve. This could be accomplished through complete reporting and stringent monitoring of shipments of wood as they leave the reserve. Such shipments should all be required to turn in adequate documentation of the number, size, and geographic source of trees removed, by species; furthermore, these reported totals should be carefully checked for veracity against the wood accompanying these "guias". In order to fully document wood leaving the reserve, it is necessary 1) that CONAP control posts exist on every important access route to the reserve, 2) that these posts be manned by CONAP personnel at all times, and 3) that all wood passing these checkpoints be inspected and its documentation verified for accurate reporting of wood shipped. At times, logging trucks leave the reserve during the night. Control posts should be manned 24 hours a day, and even nighttime shipments inspected. Concessionaires (commercial and cooperative) should be required to report, annually or more often, the number and size of trees, by species, harvested per geographic region. It will probably be necessary to verify in some way, perhaps through unannounced spot-checks, the veracity of the various kinds of reporting suggested above.

2. Value and tax revenues from wood leaving the reserve

It is desirable for CONAP to have reliable information on the economic importance of the various activities that take place in the MBR. Such information increases CONAP's ability to wisely manage the conflicting demands of varied uses of the MBR, to evaluate and report on the viability of the sustainable-use management paradigm within the MBR, and to act as an advocate for the continued existence of the MBR in a nation characterized by increasing demographic pressure and demand for natural resources.

For these reasons, CONAP should monitor the total market value of wood taken from the reserve, as well as the amount of taxes paid to federal, departmental, and municipal governments. It is questionable how best to achieve this, especially since a substantial portion of the wood market is currently conducted in an illegal and clandestine fashion. Probably the best that can be done is to require each logging company, cooperative, and sawmill to report regularly on the amount of wood bought, sold, and processed, and the amount paid and received for the same. A mechanism should be sought for routinely collecting such data. Also, CONAP should routinely solicit of the relevant government agency, information on the amount of taxes paid on wood.

Monitoring population characteristics of commercial tree species

Preferred methods:

All concessionaires should be required to do the following:

1) maintain an updated forest inventory at a specified sampling intensity, providing information on the present and predicted future standing crop of commercial species (density, volume, and size distribution).

2) periodically gather data via a standardized, approved protocol, on seedling establishment rates of target species.

3) conduct an ongoing study of survival and growth rates of different size/age classes of target species, especially of the stages prior to achieving canopy stature.

After several years of such data collection, the accuracy of models used to predict future standing crops and wood production should be substantially enhanced, through use of locally-derived data. The above methods do not require high technology, but do require rigorous experimental design and analysis, and careful field measurements. There is no simpler alternative.

2.8 Monitor trafficking of psittacines, especially Scarlet Macaws

Monitor magnitude of trafficking, using records of confiscations by CONAP authorities, data from vigilance in Flores airport and any other vigilance efforts, data from CONAP guard posts and patrol, and observations of trafficking evidence in the field. Monitoring of macaw populations is discussed in a later section.

2.9 Monitor harvest rate and indicators of population trends of hunted animal species

Ultimately our interest is in the sustainability of the populations of hunted species under observed levels of hunting pressure. Here we discuss indirect measures, based on results and impressions of hunters. In a later section we address means of directly monitoring populations of hunted species.

Preferred methods:

Methods for studying harvest rates by hunters within the MBR have been extensively tested by various workers (Roling et al. 1995, Jolón 1995, and citations therein). We recommend that the methods of these workers be used in selected villages, sampled on a rotating basis, in order to collect data on:

1. number, size, age, sex, and reproductive condition of animals killed; collect and preserve relevant animal parts for analysis.

2. hunter success per unit effort (time and distance of search effort, including specification of methods used, e.g., dogs or not); standard record sheet filled out daily by each collaborating hunter.

3. hunter impressions of population tendencies of game species; periodic questionnaire.

Villages in several parts of the reserve should be periodically monitored. Each village should be monitored for a full year, at 3-5 year intervals. It is perhaps reasonable to monitor the same villages listed under "monitoring of sustainability of lifestyles". Although hunting may play a lesser roles in many villages in areas of highly modified habitat than it does in remote forest communities such as Uaxactún, it is worth documenting the role of hunting in such altered landscapes as well. Moreover, the site where hunting takes place should be carefully documented, as many hunters may travel substantial distances from their homes in order to hunt. Detailed methods for collecting data from hunters may be obtained by consultation with Georg Roling, Mario Jolón, Julio Morales, Cecilia Morales, or others who have taken part in studies of hunting in Uaxactún or elsewhere in the region.

3. AN INTRODUCTION TO ECOLOGICAL MONITORING

In this section we focus on that class of monitoring that is purely biological or ecological in nature. In our usage, the terms biological, ecological and biotic monitoring are synonymous. Biological monitoring differs from, or is a distinctive subset of, environmental monitoring. Environmental monitoring strives to document the magnitude and effects of environmental stressors, most commonly pollutants, but tends to view the biota largely as indicator tools, rather than as an endpoint of monitoring. In contrast, biotic or ecological monitoring, while also striving to document the importance and effects of stressors, has as its primary concern the status of biological systems. This section discusses the rationale for ecological monitoring, providing conceptual background for the remainder of the document.

Ecological integrity as a conservation goal and monitoring focus

A stated objective of CONAP's management of the MBR is to "safeguard the diverse tropical ecosystems present in the MBR" (CONAP 1996). It is necessary to flesh out the notion of what would constitute such safeguarding. We believe that the appropriate goal is to maintain the full native biota of the reserve (and only the native biota) within the natural range of variation of species abundance, genetic diversity, patterns of interactions among species, and rates and patterns of ecological, ecosystem and landscape processes, over a time span of several centuries. As shorthand for the goal just stated, we consider this to be "maintaining the ecological (biological, biotic) integrity" of the MBR. While this could also be described as maintaining the natural biological diversity of the reserve, we avoid that terminology for reasons stated below.

We speak in terms of monitoring biotic integrity rather than the more traditional "biological diversity" because of confusion surrounding the latter term. In reality, our conception of biotic integrity is identical to the accepted definition of biological diversity, which recognizes hierarchical components of the latter, and which has an implicit standard of "naturalness" for indigenous biotic systems. Unfortunately, some people equate biological diversity with simple species diversity. To make matters worse, the term "diversity" in its traditional usage in ecology does not consider the identity of the species that make up a community, but only the number of species present and their relative abundance. Hence a degraded community rich in invasive, "weedy", and even alien species may have a higher ecological diversity than a pristine community that retains all its native species and natural community patterns; the latter of course is of much greater conservation interest. In contrast, the concept of biotic integrity explicitly refers to the species composition of a community and the degree to which it resembles a pristine example of that community type (Karr 1991, Angermeier and Karr 1994). For these reasons, we feel compelled to avoid the term "biological diversity" and to focus instead on biotic or ecological integrity (which terms are here considered synonymous). Rather than maximizing local species diversity, our goal is to maintain biotic integrity of the reserve.

Another possible objective would be to maintain "ecosystem health" of the reserve. The "ecosystem health" concept, however, focuses largely on physico-chemical processes and attributes such as energy flow, primary production, nutrient cycling, soil formation, hydrological function, etc., without necessarily a focus on the identity of the species playing roles within the ecosystem. By these lights, a healthy ecosystem is one that maintains its autoregenerative and creative capacity, whether or not it displays high biological integrity (Callicott and Mumford 1997). Under the "ecosystem health" paradigm, species *per se* are attributed no value except for their functional role, and may be interchangeable; in contrast, under the ecological integrity paradigm, the intactness of native biota is the primary criterion. Clearly, biotic integrity is the more relevant goal for management of the MBR, and a relevant criterion for monitoring.

As suggested above, in monitoring the biotic or ecological integrity of the MRB, we are concerned with the extent to which the reserve retains all components of its biota, from genes to landscapes and processes, within naturally occurring value ranges. In reality we cannot hope to achieve such an ambitious level of monitoring. We propose that we entirely ignore monitoring at the genetic level; while it is not without importance, the primary concern today in the MBR is the disappearance, fragmentation and degradation of entire biotic communities and species populations. Similarly, we propose we ignore ecosystem (physico-chemical) processes at this time; this topic is discussed in Appendix 12. Moreover, it is impractical to directly monitor most ecological processes. We propose that we focus attention on the composition and structure of biotic communities, i.e., at the level of species populations, and aggregations of species populations.

Logic of the use of "indicators"

Ecological monitoring relies heavily on the notion of using "indicators"--indicator species as well as other forms of indicators. In the most general sense, something that serves as an "indicator" in *any* context is believed to reveal information about a greater whole, rather than simply about itself. The linkage between the indicator and the value in which we are ultimately interested may be very direct, as in the case of an automobile's temperature gauge and the temperature of water in the engine block--or less direct, as in the fabled canary and the air in the coal mine; we observe that *something* has killed the canary, and it is likely that the air in the mine did so, though it may have been something else.

Drawing on terminology of the related field of ecological risk assessment, it is useful to distinguish "assessment endpoints" and "measurement endpoints" (Suter 1990). Assessment endpoints are the actual environmental values that we are interested in safeguarding. In contrast, measurement endpoints (synonymous with indicators) are measurable environmental characteristics that are related to the assessment endpoints or ultimate values that concern us. In the previous example, the smooth functioning of the engine is an assessment endpoint or valued trait, and its temperature is one measurement endpoint or indicator thereof; oil pressure would be another. Likewise, safe air in the mine is a valued characteristic or assessment endpoint, while the health of the canary is an indicator thereof.

In some cases, the actual values we hope to protect, i.e., the assessment endpoints, may themselves serve as indicators. Suter (1990) gives the example of the sugar maple. We may hope to guard against decline of sugar production and increased tree mortality, and these same parameters may serve as indicators to be measured. In many cases, however, it is difficult to measure the state of the environmental value we hope to protect, because it is complex or ill-defined; in such cases we often use surrogates as indicators. An example might be the ecological integrity of the forest community. Ecological integrity, by definition, includes the state values of all biotic components of the system; hence it is difficult or impossible to measure in its totality. The best we can do is to document the status of surrogates which are believed to adequately reflect the status of the ecological integrity of the whole system. In other cases, indicators may form part of a causal chain between a stressor and the assessment endpoint, as when we measure habitat loss and infer effects on a wildlife population (Suter 1990).

Logic of the indicator species approach

The use of indicator species or other biotic indicators is based on the presumption that they reveal something about the greater ecological fabric of which they form a part. Cairns and Pratt (1993) explained the indicator species concept as follows:

> "The idea that certain species can be used to indicate certain types of environmental conditions is well-established. For example, trout are associated with a particular kind of habitat. Gardeners know that plants have certain preferences regarding soil, amount of sunlight, and temperature. The presence of a species indicates that the habitat is suitable and, because some of the environmental requirements are known for many species, their presence indicates something about the nature of the environment in which they are found. Thus, the concept of the presence of species indicating certain conditions is based on practical observations verifiable by almost anyone who has contact with the environment."

These authors also caution that making inferences based on the *absence* of a species is considerably more risky, with which we agree.

History of the indicator species concept

The use of "indicator species" or "indicator assemblages" in monitoring and evaluation of environmental quality and biotic integrity has an 80-year history, marked by notable success. By far the most widespread use has been in monitoring water quality and biotic integrity of aquatic communities. The modern history of aquatic bio-monitoring began with Kolkwitz and Marsson's (1908, 1909) development of the concept of "saprobity" (degree of pollution) in rivers as a measure of organic matter (sewage) enrichment, and resultant decrease in dissolved oxygen (Cairns and Pratt 1993). Their observations of correlations between pollution intensity and the abundance and rarity of certain aquatic taxa led to development of lists of indicator organisms for different levels of water quality. The "saprobien" system has since been extended and revised repeatedly, in particular by European scientists (citations in Cairns and Pratt 1993).

This approach led to development of a variety of indices for water quality based on patterns of species occurrence. One such index is the "Index of Biotic Integrity" (IBI), which incorporates information from multiple indicators into a single numerical value (Karr 1991). The IBI incorporates data on species composition and diversity, trophic composition, population density, tolerance to human impacts, and individual health to evaluate integrity of lotic fish communities. It has been used in more than 20 states in the US and Canada, several European nations, Venezuela, and Mexico (Angermeier and Karr 1994). Similar protocols, many using aquatic invertebrates, have been used to assess ecological condition of lakes, streams and estuaries (Atkin and Birch 1991, Rosenberg and Resh 1993, Angermeier and Karr 1994, Fore et al. 1996, Kerans and Karr 1994). Note that this approach does not rely on use of one or a few indicator species, but rather, relies on a large subset of the overall aquatic biota. A key feature of this approach is that conditions observed in the system under assessment are compared to region-specific expectations for an undegraded system, i.e., the *reference condition* (Karr 1991). We propose that we emulate this approach by monitoring several multi-species groups of terrestrial organisms as indicators of forest biotic integrity.

The indicator species concept also has a strong history in plant ecology. Clements reviewed this topic in 1920, citing some 450 references (Grigal 1972). Grigal (1972) states that such a review in 1972 would have encompassed more than 8,000 references. Three properties of vegetation have been used as indicators: floristic composition of communities, plant morphology, and chemical composition of plant tissues. Clements classified plant indicators into four types of usage: (1) condition or factor indicators, reflecting environmental factors such as light, temperature, soil mineralogy, depth of water table, etc.; (2) process indicators, useful in revealing effects of natural or artificial disturbances such as fire, grazing, drought and floods; (3) practice or use indicators, suggesting site potential for agriculture or forestry, and (4) paleic indicators, i.e., use of plant fossils to make inferences about prehistoric conditions.

Plants have been extensively used in mineral prospecting, through analysis of the content of target metals in their tissues, and in the case of uranium prospecting, by assaying alpha radiation from radioactive elements geologically associated with uranium (Grigal 1972). Use of indicator species also has a long history in the field of rangeland management, where some plants (unpalatable to livestock) are characterized as "increasers" under grazing, while others are recognized as "decreasers", and still others as "invaders" in response to grazing. Relative proportions of these three groups serve to indicate grazing impacts and departure from reference conditions of light or no grazing (P. Robertson, pers. comm., Grigal 1972). Assessment of potential land uses via vegetation has been widely used, for example in development planning in Siberia (Grigal 1972). Though single plant species and plant communities have often been used successfully as indicators, Grigal (1972) cautions that the prevalent phenomenon of locally-adapted ecotypes in plants may preclude extrapolation between sites. For example, while blue grama (*Bouteloua gracilis*) was a decreaser under grazing in New Mexico, it increased with grazing in Oklahoma, while in Colorado, grazing appeared to have no effect.

Another well-known instance of biological monitoring based on the indicator species concept is that of air quality monitoring using lichens. Lichens have proven to be excellent bioindicators of air quality, revealing effects and pollution levels of sulphur dioxide, acid rain, metals, radionuclides, and chlorinated hydrocarbons; several thousand scientific papers have been published on the use of lichens as bioindicators (Richardson 1991). Lichens are used in such studies in two ways. First, pollution poisons the more sensitive species, leading to changes in community composition and structure; in this way, occurrence and abundance of particular species provides an index of atmospheric purity (Nash and Wirth 1988). Secondly, lichen tissues are analyzed to determine pollutant contents, often at different distances from pollution sources; this provides information on the size of fallout zones and chemical content of pollution.

Use of physiological indicators in monitoring

At the level of the individual, most environmental indicators used to date revolve around physiological effects of stress, or the morphological manifestations thereof. For example, Hill (1995) reviews the use of magnitude of fluctuating asymmetry of morphological traits, especially those resulting from sexual selection, as indicators of stress and environmental quality. Sexually-selected traits (mostly male ornaments and armaments) reliably indicate the physical condition of their bearer during development, and thus are responsive to environmental stresses. For example, radionuclide contamination at the site of the Chernobyl disaster is correlated with degree of asymmetry of tail length in male Barn Swallows (*Hirundo rustica*)(Moller 1993). Fluctuating asymmetry of several other, non-sexually selected, morphological traits, has also been used successfully as an indicator of environmental stress (Hill 1995). Karr (1991) and Rosenberg and Resh (1993) give other examples of environmental indicators based on individual physiological condition. We do not propose use of any such indicators at this time, although the approach, for example, in measuring canine length in male jaguars as a generalized indicator of stress, has potential; Manning (1994) made such a use of this measure in lowland gorillas (*Gorilla g. gorilla*).

Bio-indicators versus sentinel species

As is apparent in the above examples, organisms have been used in ecological monitoring in roughly two broad manners--as "bio-indicators" and as "sentinel" species. When species or species groups are used as bio-indicators, the focus is on the ways in which environmental stressors affect their populations, behavior, physiology, development, etc. In contrast, the term "sentinel" is generally applied when a species is used as a sampling device to reflect the concentration of contaminants in the environment (through concentration in its own tissues). Perhaps it would lend more clarity to use the terms "effect indicators" and "bioaccumulative indicators" for these two cases (Cairns and Pratt 1993, Johnson et al. 1993). Various organisms have been used as sentinels or bioaccumulative indicators for monitoring pollutant levels in the environment; examples include lichens, fungi, bryophytes, herbaceous flowering plants, broad-leaved and coniferous trees, fishes, birds, and mussels (Furness et al. 1993).

Other uses of the indicator species concept

A minor growth industry within the field of conservation biology has been the use of organisms as an aid in prioritizing conservation actions, for example, in deciding the relative priority of acquiring different parcels of land for reserve systems. One mode of usage might be termed that of *biogeographic indicators*. In this usage, one is concerned with locating areas of especially high endemism, uniqueness of species composition, or high species richness. Many groups, from plants to insects and birds have been employed in this way, on scales ranging from local to global (Pearson and Cassola 1992, Wege and Long 1995). Another usage has been as indicators of certain aspects of "naturalness", for example, *forest continuity*, i.e., of the extent to which forest has retained old-growth characteristics continuously since primeval times. There is a strong tradition of such usage in the Scandinavian countries; especially used have been lichens and wood-boring beetles, but other taxa including understory herbs have also been used (Bistrom and Vaisanen 1988, Vaisanen et al. 1993, Nilsson et al. 1995, Okland et al. 1996).

In this document, when we speak of the indicator value of organisms for monitoring in the MBR, we are not referring to the sentinel, biogeographic, forest continuity, or other such functions mentioned above. We are referring strictly to the ability of those organisms to reflect changes in biotic communities or environmental conditions over time, including those due to certain anthropogenic stressors.

Criticism of the indicator species concept, and a solution: multi-species "indicator suites"

The indicator species approach has been criticized by some (e.g. Morrison 1986, Landres 1988, Temple and Wiens 1989), mainly because no single species can be counted on to reliably reveal something important about the greater ecological fabric, rather than simply about its own status. This is true because many factors can affect a species' presence and abundance, resulting in its being absent from potentially suitable habitat, being concentrated in poor habitat, and other counterintuitive results. This problem is obviated by focusing not on single species, but rather, on multi-species indicator suites or complexes. And in fact, as indicated above, most use of the indicator species idea over the past 80 years has not been in such a single-species context, but has employed large groups of species as indicator suites. Use of large suites of indicators does not rely on any special property of these species, but merely on the fact that species tend to have predictable habitat requirements; hence the presence of a certain combination of species reliably indicates something about the environment where they occur. Though a single species may give an anomalous result in a given instance, especially through its absence or rarity, it is far less likely that several dozen species will do so simultaneously. Hence we lay aside all published criticisms of the indicator species concept of which we are aware, as we do not feel they apply to the approach employed here.

As indicator suites, we advocate using all the species that are adequately detected by a given sampling method or combination of methods--often 50-100 species or more. Hence the indicator suites recommended here are partly "method-based"--defined in part by the methods used to sample their abundance or demography. Such an approach, using 50-100 species of each of two or more distantly-related taxonomic groups as indicator suites is a powerful and robust technique.

Non-indicator biotic monitoring

There are other legitimate reasons for monitoring a given species or functional group, besides the indicator function described above, and lack of appreciation of this fact has sometimes led to needless acrimony. In addition to ecological indicators, Noss (1990) recognized four categories of species that may warrant monitoring: (1) *vulnerable species* (rare, persecuted, or extinction-prone), (2) *keystone species* (species pivotal in maintaining community diversity or ecosystem function), (3) *umbrella species* (those with large area requirements, so that protecting sufficient habitat for them will bring many other species under protection), and (4) *flagship species* (charismatic species that can serve as rallying points for conservation efforts). To this list, we would add (5) *economically important species*. Note that many species may qualify under two or more categories. We propose monitoring of some economically important species but do not propose monitoring any species primarily for their flagship or umbrella roles. We recommend monitoring certain vulnerable species to the extent practical. In a later section we explore in some depth the potential importance of monitoring "keystone" species. Further discussion of these species categories is found in Appendix 2.

4. MONITORING ECOLOGICAL INTEGRITY OF NEOTROPICAL FOREST COMMUNITIES

Assessing and monitoring biotic integrity in terrestrial ecosystems--developments to date

While monitoring of biotic integrity of aquatic systems has a venerable literature, efforts to monitor and assess biotic integrity of terrestrial ecosystems appear to be in their infancy. Examples in the North American literature are relatively few though increasing in number recently; apparently the field is better developed in Europe. Among the best examples we have found are some that used spiders and beetles. The Czech arachnologist Buchar (1983) categorized spiders into three groups: "relicts of the first rank", "relicts of the second rank", and "expansive" species. Expansive species are those that thrive in areas deforested by man. Relicts of the first rank are species occurring mainly in protected areas that have experienced little alteration by man. Relicts of the second rank occur in plantation forests but do not penetrate into non-forest ecosystems. A similar approach was used for beetle communities; an "index of community" was created that allowed comparison of the biotic integrity of beetle communities at different sites. Staphylinid beetle species were classified as anthropophilic, anthropoindifferent, and anthropophobic, essentially parallelling the classification described above for spiders (Bohac and Fuchs 1991). Carabid beetles have been used in many studies as indicators of habitat condition, fragmentation, etc. (Rushton et al. 1989, Kromp 1990, Niemela et al. 1993, and citations therein). While several programs for monitoring bird populations exist in North America, Europe, and elsewhere, these have, with rare exceptions, focused on the status of the bird species populations for the sake of their own conservation, rather than as indicators of environmental change; however, the potential for such usage is clear (e.g., Graber and Graber 1976). In our literature review, we did not find any example of a program that attempted to comprehensively monitor the ecological integrity of a forest ecosystem, much less a Neotropical forest ecosystem; though such efforts may exist, they apparently are not common. We are left in the position of largely attempting to invent such a system.

Neotropical forest food web structure--implications for monitoring

Before selecting indicators of ecological integrity for a tropical forest protected area, it is worth reviewing what we know of community structure in neotropical forests. Perhaps the most influential paper to date on the structure of neotropical forest food webs is that of Gilbert (1980). Some salient points from this paper are as follows. A chemical arm's race between plants and herbivores has led in many cases to insect groups restricting their diets to certain plant groups (families and genera) whose protective secondary compounds these insects are specialized to be able to tolerate. As a result, many plant groups (genera and families) are organized into more or less distinct food webs along with their specialist insect herbivores and associated parasitoids. The forest as a whole is thus organized into probably hundreds of such parallel food webs, which are linked to one another by the pollination and seed-dispersal services of "mobile link" species--mostly insects, birds and bats.

Apparently it is common that certain plant species serve as "keystone" food resources, being critical to the survival of many mobile link species through periods of resource scarcity (Gilbert 1980). The whole structure is overlain by a three-dimensional "ant mosaic" resulting from the non-overlap of territories of a few dominant ant species, with which different assemblages of subdominant ants coexist. Host specificity is such that loss of certain plant or insect species may result in loss of reliant species. In particular, loss of keystone food plants is predicted to result in loss of mobile links, which in turn may lead to loss of plant species reliant on their services, and thence to other insects reliant on those plants, along with associated parasitoids. Futuyma (1973) predicts such extinction cascades.

Does Gilbert's vision of neotropical forest community structure imply anything critical for design of a monitoring program? It may tell us the following. First, because of the subdivision of the overall community into many parallel, loosely-linked subcommunities, it does not appear that any one or few species can serve as indicators for overall community traits. However, Gilbert's vision does imply that monitoring of certain insect groups which collectively, over the many species comprising them, interact with many species of plants in host-specific fashion, should reveal much about the integrity of that entire plant-insect system. Butterflies should serve admirably for this. Many butterfly genera specialize on certain plant genera or families (DeVries 1987). Austin et al. (1996) list 535 butterfly species known from Tikal National Park and the area just to the south. Monitoring of 50 or more of these species, carefully selected using various criteria such as host plant identity, ease of identification and sampling, etc., should be an effective means of monitoring the status of a subset of the plant community (and by extension, other plant associates, especially insects). No doubt any number of different insect groups could be used in a similar fashion, especially those including many host-specific herbivores. We propose use of butterflies because research and monitoring of this insect group in the MBR is already underway (Méndez et al. 1995, Austin et al. 1996, Méndez 1997).

Gilbert's (1980) conclusions also suggest the desirability of monitoring keystone food plants. We assume this objective would be adequately covered by creation of three permanent tree community study plots suggested here. However, it could prove worthwhile, in areas that have become highly fragmented or otherwise altered, to specifically target keystone food plants for monitoring.

"Keystone species" or "strong interactors"--what are they?

In some cases, certain species exert disproportionately large influence on community composition, structure, and function, sometimes helping maintain community species diversity. Such species are often referred to as "keystone species". The term "strong interactors" might be more appropriate, since degree of influence in the community is a matter of degree rather than an all-or-none proposition; however, the keystone epithet also implies a high degree of functional non-redundancy which renders these species uniquely influential within communities. There is much ambiguity surrounding this concept (Mills et al. 1993), and in general, we do not know how many species in a given community are "strong interactors" and/or functionally non-redundant. We agree to a point with Janzen (1994) that a keystone species "is a species that you know enough about to recognize the ripples that occur when it is removed. All species are keystone species on some scale...". With adequate knowledge, we would no doubt find that many species affect community characteristics. Still, some species are less easily replaced from a functional standpoint than are others, giving them unique influence and keystone-like properties.

There are convincing examples of keystone-like roles played by predators, pollinators, seed dispersers, food plants, habitat modifiers (e.g., beavers, mound-building termites), and herbivores (Mills et al. 1993). Here we will give a few examples from Neotropical forests. The White-eyed Vireo (*Vireo griseus*), a small migrant songbird, is the most important seed disperser of the Indio Desnudo tree (*Bursera simaruba*) in the northeast Yucatán Peninsula (Greenberg et al. 1995). Similarly, a single species of bird, *Myrmotherula fulviventris*, was found to have a large effect on the populations of arthropods in aerial leaf litter in a Panamanian forest (Gradwohl and Greenberg 1982); these two examples may best be deemed moderately strong interactors rather than keystones. It has been demonstrated that certain dominant ant species exert pronounced effects on the composition, not only of the ant community, but on communities of other insects and spiders--the so-called "ant mosaic" phenomenon (Holldobler and Wilson 1990, and citations therein). Fruiting plants such as figs (*Ficus* spp.) that sustain many species of birds and mammals at some times of year have also been regarded as keystone species (Terborgh 1986).

Is there a role for monitoring of "keystone species"?

While an environmental stressor may cause many possible ecological responses, these are not of equal importance. Loss of a keystone species that plays a major role in structuring the community would be more important than loss of a species for which there are one or more "redundant" species capable of assuming its functional role. Though our knowledge of species' interaction strengths and functional uniqueness in Neotropical forests is very incomplete, we can make some educated guesses based on data and theory. The largest top predators are among the clearest examples. Their functional roles are unlikely to be subsumed by other species, should they disappear from the system. We would not expect their absence or rarity to lead to changes in total energy flow, but it may well have measurable effects on the route of energy flow through the community, and on various species interactions and community dynamics (Estes 1996).

Any species involved in highly species-specific interactions are likewise expected to be non-redundant, i.e., their roles are not likely to be subsumed by other species should they disappear. Examples would be the many specific interactions between plants and insects in tropical forests, mainly as pollinators and herbivores. Other examples are host-parasite relationships among insects. Others may include vertebrate-plant relationships of pollination and seed dispersal. The loss of species involved in such highly specific interactions may have more effect on community structure, function, and ultimately, composition, than would the loss of a species whose ecological effects are less unique.

At the other extreme, we expect decomposers to be largely redundant; though niche divergence among decomposers no doubt exists, with some perhaps being highly specific in their roles, we do not envision a massive build-up of undecomposed organic matter resulting from loss of one or two decomposing species. Likewise, generalized herbivores may be largely redundant, as may leaf-litter detritivores and insectivorous birds, insofar as the measurable effects of their activities on community structure are concerned.

Our level of knowledge of the ecology of forests of the MBR is inadequate to allow much focus on keystone species as guidelines in reserve management or as special targets of monitoring. Hence, we focus largely on methods that will provide information on large suites of species of several taxonomic groups--birds, mammals, insects, amphibians and trees. Monitoring of such diverse groups should enhance our ability to detect subtle, unspecified changes in community attributes.

Top carnivores as keystone species in Neotropical forests

In spite of the incompleteness of our knowledge of tropical forest community function, we suspect that it is important to monitor populations of certain large mammals, in particular, the largest carnivores--the jaguar and puma. These species are believed to have important effects on community structure, and are presumably extinction-prone due to their need for large habitat areas and their vulnerability to hunting. Many biologists believe that loss of top carnivores such as the jaguar and puma from Neotropical forest ecosystems can produce a cascade of ecological effects (Terborgh 1988, 1990, 1992), and some evidence supports this view with respect to effects on both fauna (Loiselle and Hoppes 1983, Greene 1988, da Fonseca and Robinson 1990, Terborgh 1990, 1992, Palomares et al. 1994) and vegetation (Dirzo and Miranda 1990, Leigh et al. 1993, but see Terborgh and Wright 1994). General and theoretical support for keystone roles of predators in communities is found in Hairston et al. (1960), Slobodkin et al. (1967), Estes (1996), and citations therein. It is thought that absence of jaguars and pumas can lead to increased abundance of medium-sized mammals (peccaries, agoutis, pacas, armadillos, white-tailed and brocket deer, and smaller predators), which in turn affect regeneration rates of tree species, rates of predation on bird nests, etc. For the above reasons, we propose methods that will allow monitoring of several species of large to medium-sized terrestrial mammals, with a central focus on the larger carnivores.

Limitations of our ability to detect unanticipated kinds of ecological change

A glance at the historical record indicates a need for substantial skepticism as to our ability to design a monitoring program that will reliably detect environmental stressors whose identity we do not anticipate. In many cases, we were not aware of an environmental problem until symptoms developed. Examples include the disappearance of mayflies from Lake Erie as a symptom of the onset of eutrophication, reproductive failure of seals in the Baltic Sea as a result of biomagnification of PCB's and other toxic chemicals, and appearance and subsequent disappearance of a population of dwarf suckers in an Ontario Lake as one of the first signs of damage from acid rain (Rapport 1989). Other examples are reproductive failure in Peregrine Falcons as a result of DDE biomagnification, and decline of forests in the Appalachians due to ozone damage. If we had designed ecological monitoring programs for these regions prior to the onset of such symptoms, would we have included components that would have revealed these changes in their early stages? Tropical forests are among the most complex ecosystems on earth; hence our goal of detecting what may be subtle ecological changes within them, due to unpredictable factors, presents a very large challenge.

The Africanized honey bee in the Neotropics provides a sobering lesson in the difficulties of detecting unknown types of change due to stressors of unanticipated nature. In this case, the bee itself is the potential stressor, and our challenge is to know how it has affected the ecology and perhaps impacted conservation goals in neotropical ecosystems. From 26 mated queen *Apis mellifera scutellata*, thousands of drones, and some African/European hybrid queens and workers released in southern Brazil in 1956, this bee has spread throughout the neotropics, colonizing 16 million square km and consuming perhaps two billion kilograms of pollen and 20 billion kilograms of nectar annually (Roubik 1989).

One might suppose that this species' introduction would have measurable ecological effects such as decline of certain native bee species, or at least changes in community structure among native bees, and perhaps effects on the pollination ecology of certain plants. Such changes may have occurred, but if so, they have not been convincingly demonstrated (Roubik 1996a, b). Moreover, the ecological effects of introduced honey bees in North America and Australia have also been difficult to demonstrate despite a fair amount of research. Despite the lack of definitive research findings, a number of bee researchers believe that honeybees do at times have negative impacts on populations of native bees (Buchmann 1996, Sugden 1996, Thorp

1996). If a large number of studies by bee researchers on three continents have been unable to demonstrate what many bee experts believe to exist, i.e., detrimental effects of honeybee competition on native bees, this does not bode well for our ability to detect subtle ecological changes via a generalized monitoring program. Even if we had been specifically monitoring native bee populations prior to the arrival of Africanized honeybees in the MBR, there is an excellent chance that we would not have detected any effect on their populations, even if it did exist.

Our conclusion from the above examples is the following: it may be exceedingly difficult to detect effects of unanticipated environmental stressors in the MBR. The likelihood that a generalized monitoring program will be sufficiently powerful to detect effects whose identity was not envisioned in the design of the program seems small indeed. This may temper our optimism about the detection power of the proposed monitoring program, and should remind us to strive for maximal statistical power.

5. SELECTION OF BIOTIC INDICATORS FOR ECOLOGICAL INTEGRITY OF THE MAYA BIOSPHERE RESERVE

Selecting indicators--basic considerations

Before proposing indicators for use in the MBR, it is necessary to discuss the logic used in their selection. In selecting indicators, EPA's EMAP program (see Appendix 1) uses the following sequence. First, environmental values of the resource in question are identified, and assessment questions which follow from those values, are formulated. The most likely stressors are identified, and conceptual models are developed, depicting the resource's structure, function, and likely response to stressors. Finally, indicators are selected for research and evaluation. We have followed essentially the same process.

Suter (1990) lists several desirable characteristics for assessment endpoints and indicators. He asserts that assessment endpoints should have social and biological relevance, unambiguous operational definition, and be amenable to prediction and measurement. Indicators should correspond to or predict an assessment endpoint, be readily measurable, appropriate to the scale of disturbance, have appropriate temporal dynamics, low natural variability, be diagnostic of the disturbance in mind, broadly applicable, standardized in measurement, and ideally, be supported by existing data sets. Noss (1990) gives the following list of desirable properties for species to be used as foci of monitoring. Such species should be sensitive enough to provide early warning, broadly distributed geographically or otherwise widely applicable, capable of providing a continuous assessment over a wide range of stress, relatively independent of sample size, easy and cost-effective to measure, able to differentiate between natural cycles or trends and those induced by anthropogenic stress, and relevant to ecologically significant phenomena. One could add that they should have well-known taxonomy, be easy to identify, and respond to stressors on an appropriate time scale. A somewhat different set of criteria are given by Johnson et al. (1993). In practice, few indicators can satisfy all of the above requirements.

Kelly and Harwell (1990) discuss several potential purposes for indicators. One purpose is to directly reveal the status of an endpoint of intrinsic importance to humans, e.g., economic or endangered species. In this case, the indicator is the same as the endpoint, as in the maple example. However, it is often desirable to detect incipient change before the valued endpoint itself is affected. Hence, a second class of indicators, highly sensitive "early-warning" indicators, is often desirable. Such indicators need not be highly reliable and may be regarded as "screening" indicators; it is permissible that they give some false positive indications. Likewise, a low signal-to-noise ratio may be acceptable. In effect, they "raise a red flag" indicating that something is amiss, and calling for a closer look to determine *what* is amiss. A further group of indicators these authors termed "sensitive" indicators, but we suggest the term "diagnostic" indicators. This class of indicators is envisioned as being highly reliable in indicating a certain kind of change; emphasis is not on rapidity of response, but on reliability thereof. Such indicators must have a high signal-to-noise ratio, and minimize false positives.

It is worth emphasizing the importance of establishing the direct relevance of indicators to the ecological endpoints of concern. Where the indicator is a species or process of obvious value to humans (e.g., an economically important species), this link is self-evident. However, when we propose to use as an indicator a species or other entity whose intrinsic value is not widely recognized by the public (for example, dung beetles), it is encumbent upon us to clearly demonstrate this indicator's relevance to species or values readily appreciated by the public.

Main environmental stressors of concern in the MBR

Most environmental monitoring programs to date have dealt mainly with monitoring the sources, concentrations, and effects of pollutants and excess nutrients, and the entire development of the field of environmental monitoring reflects this preoccupation. In contrast, our main task for monitoring in the MBR is to detect incipient ecological changes in a large area of near-pristine forest and wetlands, resulting mainly from local habitat conversion for farming and ranching. This task has scarcely been addressed in the literature on ecological monitoring and risk assessment.

The main factor threatening biotic integrity of the MBR is (1) deforestation, i.e., conversion to patently non-forest habitat (mainly pasture) or to a state of chronically interrupted secondary succession. Next in importance are (2) forest fragmentation and (3) degradation (e.g., thinning and alteration of forests by selective logging and fuelwood cutting). Conversion, degradation and fragmentation of (4) non-forest habitats, especially wetlands, will become more of a concern as invasion proceeds in western portions of the reserve. Other impacts anticipated in the MBR are the ecological effects of (5) hunting, (6) taking for the pet trade, extraction of (7) timber and (8) non-timber plant products, and (9) generally increasing levels of human presence and activity. Other potential effects are those of (10) invasion by exotic species, and (11) increasing degree of isolation of the MBR from other nearby reserves. The reserve may also be subject to global stressors such as (12) climate change, and (13) atmospheric changes including increases in UV penetration, CO_2 concentrations, and acid rain. Other potential threats include (14) pollution by organochlorine insecticides, radionuclides, or other persistent chemicals. All of these stressors have the advantage that, their identity being known to us, it is possible to make educated choices as to potentially effective indicators. More challenging is the detection of (15) detrimental impacts on the biota due to unforeseen factors, be they local, regional, or global in nature, and (16) secondary or indirect effects of any of the above. No doubt other threats can be posited, but we cannot anticipate all the factors that could eventually threaten the biotic integrity of the reserve.

Table 3 lists these anticipated threats, a guess as to their probability of occurrence at an important (i.e., detrimental) magnitude in the near future, and the priority we would assign to monitoring them, given limited resources.

Table 3. Environmental threats/stressors thought to be important in the Maya Biosphere Reserve, their perceived probability of reaching detrimental proportions, and priority for monitoring.

Threat/stressor	Probability of important impacts[1]	Priority of monitoring[2]
(1) deforestation	100 %	highest
(2) forest fragmentation	100 %	high
(3) forest degradation	high	high
(4) wetland conversion, degradation, fragmentation	high	medium
(5) hunting	high	high
(6) taking macaws for the pet trad	high	high
(7) timber extraction	high	medium/high?
(8) extraction of non-timber plant products	low	high
(9) increasing levels of human presence and activity	medium	low
(10) exotic species	high	high
(11) increasing isolation of MBR from neighboring reserves	high	low
(12) climate change	high	medium/high?
(13) atmospheric change (e.g., in UV, CO_2, acid rain)	high	medium/high?
(14) pollution by organochlorines, radionuclides, etc.	low	low
(15) detrimental impacts of presently unforeseen factors	high?	high
(16) secondary or indirect effects of any of the above	high	high

[1] Joint probability of occurrence and of impacts being of important magnitude for conservation in the MBR.
[2] In assigning priority of monitoring, the importance of related economic activities was also considered.

Divergent demands: area-sensitive species and species sensitive to within-habitat change and unknown future stresses

The Maya Biosphere Reserve presents a vast, nearly untrammeled landscape, threatened primarily by deforestation and forest fragmentation. Thus, among the effects we most wish to be able to detect are the earliest effects of deforestation and fragmentation. This implies that we should monitor some species or other indicators that are known or suspected to be exceptionally reliant upon large areas of mature forest. On the other hand, we also wish to monitor species or other indicators likely to reflect the overall ecological integrity of the forest, in the face of unknown kinds of environmental change and local, within-habitat effects. This latter need implies the desirability of monitoring one or more groups that are maximally integrated with the ecology of the forest as a whole, and diverse enough to have a good chance of revealing a variety of unanticipated changes. Because of the divergent demands mentioned above, it is convenient to use "indicator complexes" at two scales: at a "macro" scale, which serves to detect ecological changes at the landscape level, and at a "micro" or within-habitat scale, which is intended to reveal changes which are either local or pervasive, probably subtle, and not primarily indicative of landscape-level spatial changes.

Area-sensitive species as indicators of ecological integrity at the landscape or "macro" level

As stated above, among our highest priorities should be to monitor entities that are most revealing of the initial stages of degradation of a large, virtually pristine wilderness. What entities qualify for this designation? Changes in forest cover and indications of human immigration certainly qualify, and were discussed earlier. Beyond those indicators, most revealing should be the populations and success of those species that are most reliant on large areas of near-pristine habitat, i.e., those with the lowest population density and/or greatest spatial needs. To some extent, one can predict spatial requirements and population density from existing data and from body size and biology. Large organisms are often less numerous than small ones of similar taxa, those at high trophic positions are less numerous than those at lower trophic positions, and those requiring habitats of limited occurrence may often be less dense than are habitat generalist species. At our present state of knowledge, we believe that a list of area-sensitive species in the MBR would include the jaguar, puma, white-lipped peccary, harpy eagle, scarlet macaw, and possibly the tapir; in an earlier draft, we solicited nominations to this list, particularly of insects; none were received. Other species that probably fit these descriptors to a lesser extent (i.e. have somewhat higher population densities) are white-tailed deer, brocket deer, collared peccary, ocelot, margay, jaguarundi, crested eagle and other large raptors, several psittacines, ocellated turkey, great curassow, crested guan, and others, no doubt including some insects, reptiles, amphibians and plants.

In contrast, those organisms occurring at high population densities (most small-bodied organisms, e.g., reptiles, amphibians, insects, small birds, and rodents) probably do not require nearly as much area for maintenance of viable populations, while those that thrive in young successional vegetation are not threatened by current land-use trends. However, for many organisms we have little or no knowledge as to population density or dispersion. Moreover, tropical forests typically contain many species at very low population densities, in taxa as distantly related as trees and insects. Any such species may require large areas in order to maintain viable populations, and may hence be vulnerable to fragmentation if they are reliant on mature habitats. Some insects may require large areas for their conservation; for example, Euglossine bees may forage over tens of km in a single day (Janzen 1971). Still, even the most widely-ranging bees probably require orders of magnitude less space to maintain viable populations than do the mammals and birds listed above. Intra-tropical migrants may require large areas or an assortment of regional habitats for their conservation; this applies not only to birds but potentially to bats and insects. If any insects in the MBR make regional migrations as is suspected for some moths and butterflies in Costa Rica (Janzen 1983, p. 627, 1987), then habitat loss even in areas outside the MBR could affect their populations. However, little is known about insect migration in northern Petén. Some insects or other small organisms may be quite rare in the MBR, for whatever reason, and hence vulnerable to initial stages of deforestation and fragmentation; however, lack of knowledge on this topic makes it difficult to use such hypothetical species as indicators. Hence we suggest that the large mammals and birds listed above are currently the best biotic indicators of initial fragmentation effects in the MBR.

Joint occurrence of area-sensitivity and keystone roles

Any species that are both area-sensitive and believed to play keystone roles in maintaining community integrity may be of especially high importance for monitoring. As discussed earlier, a number of insects and plants are expected to play keystone roles. However, most insects and plants are probably abundant enough within local areas so that they will not be highly sensitive to early stages of deforestation and fragmentation. Plants that play keystone roles probably do not require special attention in the reserve at large, but could be a limiting factor in small habitat fragments and could thus be desirable to monitor in special cases. In contrast, several large bird and mammal species are believed to be both area-sensitive and to play keystone roles--especially the large cats--(see earlier section); these then, may be unique in combining the features of high sensitivity to early stages of habitat loss and fragmentation, and high importance for maintenance of biotic diversity and integrity of natural communities. We suggest that these species receive high priority for monitoring.

Monitoring effects of local, within-habitat change and unknown stressors--the "micro" scale

We hope to be able to detect the effects not only of those threats listed above, but also of threats currently unknown to us. We foresee these unanticipated effects as being primarily (1) indirect effects flowing from any of the stressors considered above, or (2) effects of currently known or unknown regional or global-level insults, mainly changes in climate, atmospheric chemistry, or pollutants. Since we cannot anticipate the nature of these threats, we cannot select indicators known to be most sensitive to them. We also wish to be able to detect impacts on the forest's ecological structure or function that result not from distant fragmentation, deforestation, or habitat alteration, but rather, from more local impacts of this nature. For all of the above, we need indicators of local or "within-habitat" ecological integrity.

Focusing on such hypothetical, unforeseen factors, is it possible to specify indicators that might be especially likely to reveal their effects? Since our ultimate concern is maintenance of natural values of the entire forest biota's composition, structure and function, ideal would be to use indicators that reflect such community-wide attributes. If one species or suite of species interacted strongly with all other community members, then it might serve as a surrogate for the entire community, but it is unlikely that any one or small number of species does so. The challenge then, is to select some subset of the biota (or other indicator) that can serve as an adequate surrogate for the degree of integrity of a biotic community which probably numbers in the tens of thousands of species.

We propose that we meet this challenge by monitoring community composition and structure of several diverse, multi-species assemblages of widely divergent taxonomic groups and varied life history and ecology: birds, butterflies, trees, amphibians, and medium-to-large terrestrial mammals. Through this approach, we should have a reasonable chance of detecting any sweeping changes in the forest's ecology. Our thesis is that these five groups collectively will serve as an adequate surrogate for the forest community as a whole.

We propose that we use: (1) a large segment of the bird community (some 90 species), as sampled by point counts, (2) a large segment of the butterfly community, as sampled by baited traps and visual census (Méndez 1997), (3) the tree community, as sampled by large, permanent plots of marked trees, (4) the anuran (frog and toad) community, as sampled by various methods, and (5) the community of medium-to-large terrestrial mammals, as sampled by automatic cameras and/or scent-stations where tracks are recorded. Other groups of organisms could be substituted, depending on the interest and expertise of those participating in monitoring; several alternative taxonomic and functional groups are suggested in Appendix 11. In cases where emphasis is on detecting effects of local habitat modification, we suggest that monitoring of the bird and butterfly assemblages is adequate; the tree and anuran communities are included for those cases where additional power is desired for detection of unknown, possibly global insults such as climate or atmospheric changes.

We suggest this multi-species, multi-taxonomic approach for two reasons. First, by monitoring several score of species of at least two different phyla, we are directly monitoring a significant fraction of the biota. Second, by including species with very different biology, life history, and ecological requirements, we increase the likelihood that some of them will be responsive to any stressor that causes important ecological changes within the forest. As indicated in an earlier section and illustrated in Fig. 2, butterflies often have host-specific relationships with larval food plants, leading to a high degree of integration of the butterfly and plant communities. Hence butterflies are expected to respond to factors that alter the floristic composition of the plant community. In contrast, birds are generally more affected by vegetation structure than floristics, and are expected to respond mainly to gross changes in vegetation architecture. Butterflies, being sensitive to microclimate, are also responsive to vegetation structure; hence both birds and butterflies should be sensitive to stressors such as logging, forest thinning and local fragmentation and edge effects. Amphibians and trees are suggested because of their possible responsiveness to factors such as increased UV penetration, CO_2 concentration, acid rain, and climate change. The mammal community is proposed for sampling mainly due to its sensitivity to fragmentation and hunting, but it may also help detect ecological changes stemming from other stressors.

Some species or taxonomic groups no doubt respond to certain kinds of stressors more readily than do others, and some may provide more information about the ecological status of the forest as a whole, by virtue of the ecological relationships in which they are involved. We do not, however, subscribe to the notion that there is any one species or group that is a "silver bullet" for monitoring; such arguments often reflect the taxonomic specialty of the investigator making the argument. For example, most groups of organisms probably respond to structural habitat modification such as logging or thinning, and hence it is no doubt possible to monitor effects of these activities by using any number of different multi-species suites. It may often be more important to take advantage of existing interest in monitoring certain organismic groups than to attempt to dictate which taxonomic groups are monitored. This is especially true when the investigators or organizations taking part in monitoring are expected to secure some or all of the required funding.

Target data for indicator suites--demography, density, or abundance indices?

Having selected species suites for use as indicators, one must consider what attributes to monitor. The main alternatives that suggest themselves at the population level are (1) abundance, or some indicator thereof, and (2) demographic parameters. Demographic parameters are generally superior to abundance in indicating the true status and trends of a population. However, measuring demographic parameters is also usually far more demanding than measuring some indicator of abundance. Hence we recommend documenting abundance rather than demographic parameters for all or most indicators at this time.

Once the decision to monitor abundance has been made, one must decide whether density data are needed, or whether an index of relative abundance is adequate. Information on density is generally superior for all uses; however it is also much more difficult and costly to obtain than are indices of relative abundance. Moreover, if methods are adequately standardized, indices of abundance should be adequate to reveal population changes, especially in a multi-species sampling context such as that espoused here. Hence, we recommend a focus on abundance indices rather than measures of density in most cases.

Assessing indicator properties of species suites

Before a group of species may be used as an indicator suite, its indicator properties must be documented. This entails verifying the species' responses to habitat features and to stressors of interest. We recommend assessing habitat affinities (and hence indicator properties with regard to broad habitat features) of species assemblages, at least partly through use of a multivariate technique such as Detrended Correspondence Analysis (DCA) or Principal Components Analysis (PCA). An example of this approach is depicted in Appendix 4, and similar examples are given by Kremen (1992), Johnson et al. (1993), and Norris and Georges (1993).

For birds in the MBR, The Peregrine Fund has conducted much of the necessary research; we can now use most members of the bird community as an "indicator assemblage" which collectively reveals successional status of the forest (Appendix 4; Whitacre et al. 1992a, b, 1995, Whitacre 1997). We hypothesize that patterns of abundance of bird species in different successional stages predict their vulnerability to deforestation, forest fragmentation and degradation; species common in young second-growth should be least vulnerable to such changes, while those restricted to tall, closed-canopy upland forest should be most sensitive. Similarly, the habitat affinities of a large segment of the butterfly fauna of the MBR have been demonstrated through research by CCB/CECON (Méndez 1997), permitting use of butterflies in a manner parallel to that just described for the bird community. Once habitat affinities for target taxa are known, then differences in the relative abundances of those species groups can be used to infer differences in environmental conditions across time or space. For both birds and butterflies, further tests of their indicator performance with respect to different land uses are needed.

Final comments on selection of indicators

1. "attribute-driven" versus "category-driven" objects.--Morrison and Marcot (1995) point out that it is far better to monitor "attributes-driven" objects than "category-driven" objects, for example, to monitor canopy height rather than categories such as "old-growth" or "non old-growth". This is especially important since our definitions as well as the factors we regard as important, may change over time. Data on canopy height or other objective traits can be reconsidered in a different light, while traits conceived in a category-driven fashion likely cannot.

2. customizing for different areas in the MBR.--It may be desirable to tailor choice of indicators and sampling methods to conditions in different parts of the MBR--for example, in the wetlands of Laguna del Tigre, special indicators and sampling methods may be appropriate.

6. AN ECOLOGICAL MONITORING PLAN FOR THE MAYA BIOSPHERE RESERVE

Table 4 presents potential components of an ecological monitoring plan for the Maya Biosphere Reserve. In the interest of thoroughness, included are all the main threats or environmental stressors thought to be important in the MBR, including several of a regional or global nature that are beyond the ability of reserve administrators to influence.

Table 4. Outline of main threats/stressors in the MBR, proposed indicators, sampling methods, and priority for monitoring.

Threat/stressor/assessment endpoint to be monitored	**Indicator**	**Sampling methods**	**Priority**
GLOBAL SCALE			
1. Climate change			
* direct measurement	* weather data	* weather stations	low
* ecological effects	* phenology of forest trees	* phenology study plots	med
	* growth and survival of forest trees	* permanent plots, marked trees	high
2. Atmospheric changes (acid rain, increased CO_2, UV penetration)			
* direct measurement	* none proposed		
* ecological effects	* amphibian (anuran) population trends, demography	* census at breeding sites, possibly transects, acoustic census	high
	* growth and survival of forest trees	* permanent plots, marked trees	high
3. Pollution by organochlorine insecticides, other persistent chemicals, radionuclides			
* direct measurement	* tissue levels in species at high trophic levels	* assay residue loads in resident forest interior insectivorous birds	low
	* patterns of pesticide use in MBR and vicinity	* informal consultation with farmers, agricultural suppliers	med
* ecological effects	* tissue burdens, degree of eggshell thinning in spp known to be susceptible	* Orange-breasted and Bat Falcons	low
REGIONAL LANDSCAPE SCALE			
4. Deforestation, forest fragmentation			
a. magnitude, rate, locality	* measures of cover change	* remote sensing, GIS, cover change detection methods	highest

	* measures of connectivity	* Fragstats, other connectivity programs * visual inspection of cover change image	low high
b. direct ecological effects	* response of area-sensitive species: jaguar, puma white-lipped peccary harpy eagle scarlet macaw raptor community psittacine community	 * automatic cameras, scent/track stations; question local people * resource guards collect sighting/sign/interview data on patrol * investigate reported sightings * monitor, size, nest occupancy, success of known nesting concentrations; search for more nesting areas * canopy-emergent and pre-dawn point counts * canopy-emergent point counts	 highest med high high high high
c. indirect ecological effects	* response of species/processes affected by changes in abundance of top carnivores: * abundance of medium-to-large mammals * demography of tree seedlings * predation rates on understory bird nests	 * automatic cameras, scent/track stations * experimental study, including use of exclosures * comparison of different areas	 highest low/med low/med
LOCAL (WITHIN HABITAT) SPATIAL SCALE			
5. Deforestation, forest fragmentation (ecological effects)	* bird community * butterfly community * med-to-large terrestrial mammals	* 5-10 minute point counts * visual census and bait-traps * automatic cameras, scent/track stations	highest highest highest
6. Forest degradation (selective logging, firewood	* bird community	* 5-10 minute point counts	highest

cutting) (ecological effects)	* butterfly community * med-to-large terrestrial mammals	* visual census and bait-traps * automatic cameras, scent/track stations	highest highest
STRESSORS THAT DO NOT CONFORM WELL TO SPATIAL HIERARCHY			
7. Subsistence hunting (ecological effects)	* guan, curassow, ocellated turkey * med-to-large terrestrial mammals	* 5-10 minute point counts, pre-dawn point counts * automatic cameras, scent/track stations	highest highest
8. Trafficking in psittacines * population effects	* Scarlet Macaw * other psittacines	* monitor size, nest occupancy, and success of known concentrations; search for more nesting concentrations * canopy-emergent point counts	high high
9. Unpredictable effects of unknown future stressors	* bird community * butterfly community * amphibian community * tree community * med-to-large mammals	* 5-10 minute point counts * visual census, baited traps * census at breeding sites, possibly transects, acoustic census * permanent plots, marked trees * automatic cameras, scent/track stations	highest highest highest highest highest

An ecological monitoring plan for the MBR--discussion of main stressors, suggested indicators, sampling methods, and priority

Following the sequence of Table 4, here we give the rationale for monitoring these stressors, justifications for use of proposed indicators and sampling methods, and the relative importance we would assign to each such monitoring effort. We proceed in a spatial hierarchical sequence, from global to local.

Global Scale

1. Climate change - There is increasing suspicion that the greenhouse effect has begun to cause global warming, and that this trend will continue over coming decades. This or other climate changes may have profound impacts for conservation efforts, for example, by causing shifts in geographic distribution of species in accordance with their physiological tolerances or performance. It would be a valuable addition to global monitoring efforts if monitoring within the MBR could contribute toward measuring the ecological effects of climate change. We regard this as a low priority relative to more urgent monitoring needs associated with preventing the imminent deforestation of the reserve. We give this theme a medium priority, but would give it a high priority if it could be achieved without draining funds from other more urgent monitoring activities. We suggest a policy of encouraging and facilitating such efforts by other investigators where possible. The possibility of local climate change in and near the MBR, e.g., resulting from regional deforestation, is also important to the conservation success of the reserve, and is a more compelling reason for efforts to document weather and climate patterns in the MBR.

A conceptual model of the effects of climatic and atmospheric stressors on trees and amphibians is presented graphically in Fig. 1.

Preferred methods:

a. Direct measurement

To document climate change, meteorological data from weather stations is presumably useful. Such data are routinely collected by several INSIVUMEH weather stations in and near the MBR. These data could, for example, reveal local changes in temperature and rainfall resulting from local deforestation or from global changes, and should be periodically acquired and entered into the monitoring database for the MBR. Several respondents who contributed ideas to this plan advocated expansion of the existing network of weather stations in the MBR. It was commented that INSIVUMEH would probably provide equipment if someone else could fund salaries for those who would collect data. This seems desirable, but should be viewed as a long-term commitment; a firm vision of long-term sources of salaries would be important, as there is little use in accumulating short runs of a few years' weather data at multiple points within the reserve. There is not, to our knowledge, a cheaper or simpler method to expand the weather and climate data base for the MBR. However, it may be that satellite platforms provide data that would be useful in such an effort.

b. Ecological effects

Preferred methods:

To detect ecological effects of climate change, we recommend two approaches:

(1) monitoring of phenology of forest trees - This could be accomplished via a simple plan whereby many individuals of several tree species are tracked throughout the year on a long-term basis. A couple cautions about experimental design are in order. First, the focus should be on sampling an adequate number of individuals of each focal species, rather than sampling every individual within a certain area; however, focal individuals should then be randomly selected. Second, focal trees should either be restricted to one topographic position and soil type, or selected so as to represent the range of such conditions available, in a stratified manner; the latter is probably best, as climatic or weather change may, for example, affect trees in more xeric sites and not in more mesic sites. Species selected for inclusion should represent a variety of families and life history traits, for example flowering and fruiting strategies. In selecting sample sizes, local variability should be assayed via preliminary sampling, and expected levels of variability should be garnished from the literature and consultation with scientists with prior experience in this topical area. If intraspecific variability is high, it would be best to limit the number of species sampled in order to permit a large number of individuals of each to be included. We assign this a medium priority.

(2) longterm monitoring of growth, mortality, and community composition of forest trees - The utility of studying the forest tree community as an indicator of climatic change is illustrated by Condit et al. (1996), who found that a 25-year drying trend is having "an obious impact" on a forest studied in Panama, with several species apparently headed for extinction within their study plot. This effort should employ permanently-marked trees in fairly large permanent plots within large blocks of well-protected forest, for example within core zones such as Tikal National Park. Though such studies typically use large plots, e.g., up to 25 ha., it seems quite possible that smaller plots could validly be used, perhaps allowing replicate plots with the same total amount of expense and effort. The key question would appear to be what size plot is needed to achieve adequate samples of several tree species; the rarest species will never have large samples on a study plot of manageable size. Such a study could also be conducted using focal individuals of selected species, as suggested above for phenology studies. However, there are advantages to marking and monitoring all individuals above a certain diameter within a defined plot: (1) this permits analysis of spacing and the competitive neighborhood, which affect mortality, growth and regeneration, and (2) it allows documentation of the species composition of the tree community, which may be the key response variable allowing detection of certain kinds of ecological change. Ideally, up to three such longterm plot studies would be established within the MBR. One study that

could partly serve this function is underway at Tikal, by Mark Schulze, Ph. D. candidate at Pennsylvania State University. Methods for such studies are described, and pros and cons discussed, in Dallmeier (1992), Condit (1995), Scheil and May (1996a, b), Clark and Clark (1996), Condit et al. (1996), and in various earlier papers by Robin Foster and Steven Hubbell (e.g., Hubbell 1979, Hubbell and Foster 1990). Such an effort is also ecologically interesting from other standpoints, and we assign it a high priority.

2. Atmospheric changes (acid rain, increased CO_2, ozone thinning and increased UV penetration)

Atmospheric CO_2 concentrations are now 25 % higher than pre-industrial revolution levels, and, if current trends continue, will double by the mid- to late 21st century (Fajer et al. 1989, Cunningham and Saigo 1995). Potential ecological effects are not limited to those of greenhouse-induced global warming, but include other direct and indirect effects of CO_2 enrichment, as discussed below. Acid rain is not, to our knowledge, believed to be a problem in Petén at this time. Ozone thinning and attendant increases in ultraviolet light penetration could have ecological effects in Petén now or in the future.

a. Direct measurement

We see no reason to suggest direct measurement of these factors in the MBR, though it could be of interest to gather a modicum of baseline data on acidity of rain.

b. Ecological effects

It is much more relevant to consider documenting ecological effects of these factors in the MBR. For this purpose, we recommend monitoring amphibian (anuran) population trends, as well as survival and growth rates of forest trees.

a. monitoring anuran populations - For years biologists in different parts of the world have known that species of frogs, and in some cases salamanders, seemed to be in decline, and by 1989 there was general concern about this phenomenon (Heyer et al. 1994). In 1990 a workshop on amphibian declines was held by the U.S. National Research Council, results of which verified that amphibian species in many parts of the world had indeed declined, some perhaps to extinction. While some regions and habitats were affected, others were not. No single factor explained the declines, though habitat destruction and general environmental degradation were implicated in many cases. Some research has demonstrated the susceptibility of frog eggs to certain forms of ultraviolet radiation, which is increasing due to thinning of the stratospheric ozone layer (Long et al. 1995, citations therein); this discovery is sobering, as points out the possibility of any number of global-scale biotic effects of ozone loss.

The preceding account suggests that it would be valuable to monitor amphibian populations in the MBR. Such efforts would be especially valuable in testing the generality of global-level factors such as increase in UV light, since most potential local causes of declines could be ruled out in the large, near-pristine area of the MBR.

Preferred methods: Sampling methods are discussed in Appendix 9. Briefly, we propose (1) census at breeding sites, and possibly (2) visual transects through the forest (day and night), and (3) acoustical census via point counts or transects. We assign this effort a high priority.

b. Survival and growth of forest trees - CO_2 concentration is commonly a limiting factor for photosynthetic rates, and plants respond to enriched CO_2 environments by increasing growth and water-use efficiency, while nitrogen concentrations in leaves may decline, affecting interactions with herbivorous insects (Fajer et al. 1989). All of the above imply that, as atmospheric CO_2 concentrations continue to rise, growth rates of plants may increase, with unknown effects on natural communities. As different plant species are likely to exhibit individualistic responses to changes in CO_2 concentrations, shifts in competitive balance are to be expected, with resultant effects on community composition and structure. This alone makes it interesting to monitor growth rates and survival of the forest tree community of the MBR, but other factors also argue for such an approach. Since we know little about present and future changes in atmospheric composition and processes, and less about their ecological effects, this would seem to argue in favor of monitoring broad features of the biota that may respond slowly and subtly but in profound ways. This suggests monitoring effects on plant communities, the primary producers which sustain nearly all life on earth.

Preferred methods: Methods, using individually marked trees on permanent study plots, are described above under "Climatic change". We assign this a high priority.

3. Pollution by organochlorine insecticides, other persistent chemicals, or radionuclides

Though generally organochlorine insecticide use is decreasing worldwide, these chemicals are still heavily used in some cases. Organochlorines have been heavily used in the past in Guatemala and neighboring countries, especially in connection with cotton farming on the Pacific coast of Guatemala, Chiapas and El Salvador. Apparently DDT is still manufactured in Mexico (L. Kiff, pers. comm.). However, organochlorines are not, to our knowledge, heavily used in the vicinity of the MBR, though this could change as farming practices become more intensive.

If one were to monitor pesticide contamination in the MBR, we would recommend assaying residue levels in resident, forest-interior wildlife of high trophic position. Appropriate would be insectivorous birds or lizards; we recommend use of understory insectivorous birds. Further, we would recommend documenting residue levels and reproductive success in the Bat Falcon (*Falco rufigularis*), an abundant, bird-eating raptor known to be susceptible to DDE-induced eggshell thinning (Kiff et al. 1980); this would reveal high levels of DDE contamination if such were to occur. However, we have no reason to suspect that chemical contamination is a special concern in the MBR. DDT contamination apparently has not been a problem in the MBR, at least in recent years; if it were, we should have noticed poor reproduction due to eggshell thinning in the Bat Falcon. We (The Peregrine Fund) have observed nesting of this species consistently since 1989 at Tikal, with no evidence of high rates of reproductive failure. Hence, at the present time, we do not see a need for monitoring of chemical residues in the MBR. Rather, we recommend the following more general approach.

Recommended methods: Monitoring personnel should question local providers of agricultural chemicals in the Flores/San Benito area, every two to three years, as to the quantities of organochlorine chemicals sold in the area. A list of generic and trade names should be compiled to aid in this effort. NGO's specializing in agriculture (e.g. CARE, Centro Maya) should report periodically (perhaps every 2 years) to the monitoring center, their general observations as to the kinds and amounts of insecticides and other biocides being used in agriculture in and near the MBR. All NGO personnel and resource guards working in the area should report to the monitoring center any observations that suggest problems with insecticides or other chemicals in and near the MBR. This informal approach should be adequate to reveal whether it becomes important at some point to conduct a study of residue levels in the environment or of pesticide use practices in and near the MBR.

Any monitoring of radionuclides presumably would be part of a multinational effort on the part of some agency with the requisite expertise and interest; we do not address this topic further.

Regional Landscape Scale

4. Deforestation and forest fragmentation at the landscape scale

a. magnitude, rate, locality - These are all best measured via remote sensing and GIS, as is being done by Dr. Steve Sader of the University of Maine, in collaboration with NASA and Conservation International. Measuring rates and areas of deforestation is the highest priority monitoring task for the MBR, and was covered in the earlier section on "Monitoring related to human activities."

Formal analysis of degree of fragmentation and connectivity is of substantially lower importance than is documentation of deforestation rate. To a large extent, degree of fragmentation can be gauged simply by visual inspection of cover change detection images. Formal analysis could be undertaken for areas where it seems appropriate, using computer programs such as "Fragstats" and others to quantify fragmentation and connectivity. However, we would rather see equivalent funding spent in gathering additional field data on other topics, for example in monitoring amphibians and permanent plots with marked trees.

b. Direct ecological effects - Such effects are best documented by examining the response of area-sensitive species; the following species in the MBR are regarded as area-sensitive. Sampling methods are described in appendices; here they are merely listed.

1. jaguar, puma, other carnivores (automatic cameras, scent-stations; evidence during resource guard patrol; question local people)

2. white-lipped peccary (evidence during resource guard; question local people)

3. harpy eagle (question local people; investigate reported sightings)

4. scarlet macaw (monitor size, nest occupancy, and success of known nesting concentrations; find additional concentrations)

5. raptor community (30-35 species) (canopy-emergent and pre-dawn point counts)

6. psittacine community (8 species) (canopy-emergent point counts)

We regard all of the above to be of high priority.

c. Indirect ecological effects - In an earlier section, we have argued that large carnivores likely exert strong influences on the composition and patterns of relative abundance of the small-to-large mammal (and other) species upon which they prey. We also argue that, when populations of large carnivores are altered by habitat fragmentation or shrinkage, or by hunting, this may lead to changes in the population changes of these smaller species, which may, in turn, lead to other changes in the community. Such indirect effects are addressed here. A conceptual model of direct and indirect effects of habitat shrinkage, fragmentation and hunting is presented graphically in Fig. 3.

To detect indirect effects of changes in abundance of large carnivores, one could monitor:

1. abundance of medium-sized to large mammals (automatic cameras, scent-stations). High priority.

2. demography of tree seedlings (experimental studies of seed predation and dispersal, studies of tree species establishment and survival, including use of exclosures). Medium priority.

3. predation rates on understory bird nests (comparison of areas that differ in abundance of top predators). Medium priority.

The first indicator listed above should, we feel, be employed. The other two are also very important research questions, and potentially could tell us more of the ecological integrity of the MBR than perhaps most other indicators proposed in this document; it is debatable whether they should receive lower priority than some other monitoring objectives recommended herein. If these objectives are attempted, they should employ "treatment" and "control" situations to the extent possible; i.e., sites where top predators are likely to have been impacted by forest fragmentation or other factors, and sites where their populations are thought to be maximally protected from such factors and from hunting.

Local (Within-Habitat) Spatial Scale

5. Deforestation, forest fragmentation - ecological effects

Proposed indicators are:

** bird community (90 species of forest birds): a general indicator assemblage for forest integrity*

Preferred methods: 5-10 minute point counts

Appendix 3 gives detailed methods for monitoring a large subset of the forest avifauna via point counts. This broad subset of the bird community will serve the function of "micro"-scale monitoring (local, within habitat).

For example, understory insectivorous birds often respond to subtle, local effects such as those caused by selective logging (Thiollay 1992, Johns 1991). The program described in Appendix 3 could be extended into a regional or nationwide monitoring effort, patterned after the Breeding Bird Survey of the US.

Other vertebrate taxa could be substituted, for example bats, rodents, amphibians or reptiles. However, none of these groups possess the advantages of the bird community. Bats may also be useful in this role, inasmuch as they are diverse in Petén's forests, have diverse food habits, and have been shown to be useful as ecological indicators (Fenton et al. 1992). However, use of bats has distinct disadvantages: (1) it would require extensive mist-netting, which is more labor-intensive for a given sample size than is use of point counts, (2) it would require rabies immunization and precautions, including follow-up medical attention to inevitable bat-bites, and (3) the knowledge required for species identification is less widely available in the scientific community than is the equivalent knowledge of birds. Rodents have been used as habitat indicators in Petén's forests (Roling 1992), but are not diverse there; we feel that this lack of diversity limits their utility as ecological indicators. Amphibians and reptiles are potentially useful as they are diverse; however, they are much more difficult to adequately sample than are birds, which argues against their use as a key hub of the monitoring program. In spite of these drawbacks, substitution of any of these groups might be desirable if there were special interest in these groups on the part of particular investigators or institutions who plan to play a major role in monitoring. However, the likelihood of a sustained role over a many-year horizon should be considered.

* *butterfly community: a general indicator assemblage for forest integrity*

Preferred methods: Sampling via visual census and baited traps (see Méndez 1997 and Appendix 8).

We recommend using the butterfly community as an indicator of forest integrity, especially since such monitoring efforts are already underway in the MBR (Austin et al. 1996, Méndez et al. 1995, Méndez 1997). Because the butterfly community collectively relies on many plant species, often with a high degree of host specificity of larval food plants (Devries 1987), it should reflect the floristic composition of the forest, as well as responding to changes in local micro-climate occasioned by habitat alteration or more widespread climate change. This tight linkage between butterflies and the composition of the plant community should make the butterfly community a sensitive indicator complex for a variety of environmental changes. In addition, butterflies appear more sensitive, overall, than do birds to subtle, local habitat modifications, making them especially useful as indicators for local, within-habitat effects (Méndez et al. 1995). Butterflies are well-known taxonomically, many species are easy to identify, and sampling methods have been developed and tested; these factors all make butterfly sampling practical (Sparrow et al. 1994, Daily and Ehrlich 1995, Méndez et al. 1995, Méndez 1997, N. Haddad, pers. comm.). Moreover, information on seasonality of occurrence and habitat association for butterflies in northern Petén exists (Austin et al. 1996, Mendez 1997), providing the essential background information to assist in monitoring efforts. Techniques of butterfly monitoring are also discussed by Hill et al. (1995) and Natuhara (1996); other sources for butterfly sampling methods are listed in a special section at the end of the Literature Cited.

* *other insect groups*

Many other insect groups could equally well be substituted for butterflies. Primary requisites are that the group be (1) locally diverse, (2) easily sorted to species with minimal training, (3) well-known taxonomically, (4) easily and reliably sampled, (5) typified by fairly stable population dynamics, and (6) that the group's biology and ecological relationships with other organisms be understood at least to some degree. Taxonomic groups to be sampled could be partly determined by sampling methods. A host of alternative insect groups for monitoring are suggested in Appendix 11, along with suggested sampling methods. One group that has been used for research and monitoring in the MBR are the dung and carrion beetles (Coleoptera: Scarabaeidae)(Méndez 1997).

All of the above monitoring efforts are regarded as high priority.

6. Forest degradation (selective logging, firewood cutting) - ecological effects

We propose we use the same indicators and methods given above:

** bird community - 5-10 minute point counts*

** butterfly community - visual census and baited traps*

This effort is of high priority.

7. Unknown effects of unanticipated stressors

As discussed earlier, our approach is to monitor community composition and structure of multiple taxonomic groups of distant phylogenetic relationship and varied biology. We propose the following indicators:

1. bird community - 5-10 min pt counts

2. butterfly community - visual census, baited traps

3. amphibian community - visual/aural transect census, census at breeding sites

4. forest tree community - permanent plots with marked trees

5. medium-to-large mammals - automatic cameras, scent-stations with track plates

We regard the above as a crucial part of the overall monitoring effort.

<u>Monitoring tasks that do not fit well into the hierarchical spatial approach</u>

8. Subsistence hunting (ecological effects)

Monitoring of performance aspects of hunting was discussed in an earlier section. Here we focus on the ecological effects of hunting.

a. direct effects (on hunted populations)

Preferred methods:

1. abundance of hunted birds (guan, curassow, ocellated turkey): 5-10 minute point counts and pre-dawn point counts.

2. abundance of hunted mammals (paca, brocket deer, white-tailed deer, white-lipped peccary, armadillo, collared peccary, agouti, coatimundi, tapir) - automatic cameras, scent-stations, track search, resource-guard patrol observations, interview.

3. demographic indicators for hunted species - take data on age, sex and reproductive condition of animals taken by hunters; via groups of cooperating hunters in focal villages.

These efforts are assigned a high priority.

b. indirect effects

1. demography of seedlings of tree species - Some evidence exists that changes in abundance of seed predators/dispersers such as agoutis (*Dasyprocta punctata*) and pacas (*Agouti paca*) can lead to changes in regeneration of tree species and shifts in tree community composition (Terborgh 1992, Leigh et al. 1993, Terborgh and Wright 1994). Hence, it would be reasonable to look for such changes in response to hunting, in particular of the paca, which is among the most heavily hunted game species in the MBR (Roling 1995).

Preferred methods:

1. This would entail comparison of sites known to differ in hunting intensity, and/or experimental studies of seed predation and dispersal, and studies of tree species establishment and survival, including use of exclosures. Leigh et al. (1993) gives an example of methods for a retrospective study comparing various sites. Such an approach could be used, for example, along a transect from the periphery to the heart of a core zone such as Tikal National Park, if there is confidence that hunting intensity varies in a monotonic fashion over such a transect. Terborgh and Wright (1994) give an example of an experimental approach using rodent and large mammal exclosures to document effects of these two groups on seed and seedling survival. Though a fascinating research topic, we rank this as a low priority task in view of overall monitoring needs; such research could be encouraged among graduate students or others desiring to conduct research in the MBR.

9. Effects of trafficking in psittacines

Monitoring of trafficking activities was discussed in an earlier section.

1) population effects of trafficking

* *Scarlet Macaw* - monitor population size, nest occupancy and success at known nesting concentrations; search for additional nesting areas to incorporate in the sample.

* *other psittacines* - canopy-emergent point counts (see Appendix 3).

10. Other species that are rare, endangered, or vulnerable in the MBR.

Species that may be regarded as rare, endangered or vulnerable in the MBR, and which were not proposed for monitoring under another section above, include the Harpy Eagle, Tapir, Orange-breasted Falcon, Morelett's Crocodile, and Jabiru. Monitoring and research on the above species should be encouraged and supported when possible. All of them except the falcon probably indicate large areas of undisturbed habitat; the falcon merits monitoring by virtue of its extreme rarity in the MBR and the republic. Most of these species are difficult to monitor; hence we do not recommend their incorporation into the core monitoring program, except through information collected by resource guards and others (by observation and interview) during patrol and other field activities, with the following exception. Known Orange-breasted Falcon nesting sites can be monitored with minimal effort, and we recommend that such efforts (underway by The Peregrine Fund) continue.

11. Introduced species

Monitoring exotic invaders may be important; the monitoring group should evaluate cases as they come to light, as to the importance of possible monitoring efforts. Initially, anyone working in the MBR or vicinity should report to the monitoring center the names of any exotic plant or animal species known to occur, and especially, to be increasing in abundance in the area. The only alien species in the MBR that we have reason to believe may be adversely affecting conservation values are the africanized honeybee and the fish *Tilapia*. Two Scarlet Macaw nest cavities at El Peru were recently occupied by these bees (Santiago Billy, pers. commun.); whether this phenomenon is contributing to decline of macaw populations in the MBR is unknown. A number of alien plant species used ornamentally and agriculturally are present in the reserve, but we are not aware of any particular threat to the biota posed by them; we have also heard that Eucalyptus is present in or near the reserve but cannot comment on whether this presents a threat. We have heard that *Tilapia* have been introduced into Lake Petén Itzá; we do not know how this might alter the lake's biotic community. It does seem clear, however, that the further spread of this species in waters of the MBR is to be strongly discouraged.

12. Endemic species

Although the MBR is not recognized as an area of great endemism, some species are endemic to the basal portion of the

Yucatán Peninsula and some may be endemic to northern Petén or the MBR. Endemic species are often, by virtue of their restricted geographic range, inherently vulnerable to human activities. A list of endemic species occurring in the MBR should be compiled, updated as necessary, and evaluation should be made as to risks to them and the need to monitor their population status.

13. Wetlands

Wetlands require specifically tailored monitoring approaches. In particular, it may be desirable to examine water quality, focusing on chemical aspects, including those that would reveal any effects of the petroleum industry, which is active in the wetland regions of Laguna del Tigre.

7. DESIGN CONSIDERATIONS FOR AN ECOLOGICAL MONITORING PROGRAM FOR THE MBR

One of the most difficult questions regarding monitoring in the MBR is how much to monitor when and where--i.e., the allocation of sampling effort 1) geographically, 2) by management unit, 3) and temporally. Moreover, different facets of monitoring may need to be adjusted differentially with regard to these spatiotemporal variables. In addressing this dilemma, it is important to consider the recent, current, and projected spatial patterns of change (mostly deforestation) in the MBR; certain areas are being rapidly deforested while others remain pristine or nearly so (Sader et al. 1994).

A. Spatial allocation for different kinds of indicators--a hierarchical, limiting-factor approach

We recommend a hierarchical, "limiting factor" approach to monitoring in the MBR. The first overall limiting factor for conservation in the reserve is existence of the native vegetative cover. The existence of forest cover is not a *sufficient* condition to guarantee the presence of all pertinent fauna and flora therein, but it is a *necessary* condition for many species; ie., the forest must be there before those species might be present. There is little reason to carry out monitoring of ecological subtleties in areas where deforestation is rapidly occurring; what does it matter that ecological imbalances might be obtaining at the periphery of such deforestation fronts, when the forest there will soon be gone? For areas of rapid deforestation, the focus should be on the factors directly related to deforestation and that might help in efforts to slow it, e.g., socioeconomic factors, farming practices, size and growth rate of human populations, sources of immigrants, etc.

Global change indicators.--At the other extreme, if any parameters related to global change are to be monitored (for example amphibian populations or growth and survival of trees), it only makes sense to do this in the most pristine and well-protected sites. Such sites are likely to remain unaffected by deforestation and direct modification for a long enough time to yield useful results, and are likely to be well-enough insulated from local stressors to be able to reveal the effects of subtle, global stressors.

Indicators of within-habitat change.--The remaining considerations are more difficult. Where, for example, is it appropriate to monitor bird and butterfly communities? These indicator suites were chosen for their ability to reveal subtle effects of local habitat modification, and hopefully to reveal effects of stressors of unpredictable nature which may crop up in the future. Again, it hardly makes sense to use these indicator groups to reveal that deforestation is occurring, as the latter is better demonstrated via remote sensing. These groups should be useful, however, in documenting the progressive modification of those parts of the reserve subject to anthropogenic modifications. For example, they should help answer the question of how much of the forest biota persists as the landscape become progressively more deforested. Hence, areas subject to ongoing habitat conversion and degradation are appropriate sites for monitoring these groups. This would include areas subject to expansion of farming and ranching (mainly in the buffer zone), as well as concessions in the multiple use zone, where activities including logging result in habitat modification. In addition, to detect effects of currently unknown stressors, especially regional or global ones, these groups should be monitored in pristine, well-protected sites such as core zones.

Area-sensitive species.--As indicators of the initial stages of habitat loss and fragmentation, we have proposed the community of medium and large mammals as our main indicator complex, supplemented by the psittacine and raptor communities. Declines in populations of these species are predicted to be among the earliest biotic effects of deforestation and forest fragmentation. Presumably the fragmentation of peripheral areas of the reserve would have little effect on the populations of these species occupying the remaining large areas of undisturbed habitat within the reserve, *until* fragmentation begins to isolate these remaining very large habitat blocks from one another. It is difficult to known where best to monitor these area-sensitive species, as we do not know at what scale fragmentation will begin to depress the reserve's carrying capacity for these species. Certainly it seems important to monitor them within some core zones, for some of these species may prove so area-sensitive, that their populations may decline even within intact core zones, as fragmentation proceeds in the surrounding areas. Hence we recommend monitoring these species in three core zones.

It would also be valuable to monitor these species across the ecotone between extensive, pristine forest, into the increasingly altered landscape, in order to document the way in which these species respond to increasing impacts along such a continuum. In effect, such a gradient study has been carried out for raptors and psittacines by The Peregrine Fund along a transect from Tikal National Park south through the buffer zone to Capulinar. We recommend duplicating this effort elsewhere in the reserve, along six or more such gradients from pristine to highly-modified landscapes in different portions of the reserve.

B. Allocation of sampling effort by management units

Detection of change within Core Zones.--We believe that monitoring should take place in core areas, multiple use zone, and the buffer zone. While it is doubtful that any part of the MBR is totally devoid of human activities such as xate harvest and hunting, the core zones presumably should remain the closest approximation to pristine ecosystems in the MRB. Research and monitoring within them should provide benchmark data representing biotic characteristics under natural or near-natural conditions. Monitoring of core areas is important in its own right, to help protect them, and also in providing "control" data against which to compare results obtained in the multiple use and buffer zones, where one can anticipate greater anthropogenic impacts.

Because core zones are not expected to be fully-protected "control" areas, special measures must be taken in order to evaluate the degree of change within even these supposedly inviolate areas, for which there are no truly unimpacted sites to serve as comparisons. Hence, sampling within core zones should be organized so as to help evaluate the degree to which they are impacted by human activities. To achieve this, we recommend that all or most sampling within core areas be stratified in the following way: sampling near the periphery (outer 1/3 of radius), sampling in the core (inner 1/3 of radius), and sampling in the intermediate portion--or sampling over a continuum from center to periphery. Either of these designs should allow detection of monotonic variation from center to periphery of the core zone, such as might be produced by any factor that is degrading the core area from the periphery.

Stratified sampling of the entire reserve--a practical impossibility?--The allocation of monitoring effort to specific sites may depend on many factors, both theoretical and practical. As noted earlier, we hope to monitor both impacts of management, and baseline tendencies (i.e., irrespective of management zones). For the latter purpose, monitoring ideally would take place at hundreds of sites within the MRB, randomly selected either from the reserve as a whole, or after stratification by geography, management zone, and perhaps community type. Such a random allocation of sampling would satisfy statistical assumptions, facilitating extrapolation of results to the reserve as a whole, as well as comparison of management units.

A pure version of this approach is probably impossible, as many random points would fall in remote areas, impractical to access without extensive helicopter use. A modified version may be possible, however, constraining the random choice to sites with some degree of access by road and river. However, because of the sheer size of the reserve, it is probably not realistic to think that any indicator may be sampled at a high enough intensity to claim adequate characterization of the entire reserve, except in the case of cover change detection via remote sensing. Rather than attempting such comprehensive coverage, it is probably best in all or most cases to aim for a more adequate monitoring of a few sites, under the hopes that these will reflect trends at other, similar portions of the reserve. For only one of the non-remote sensing indicators proposed here is there perhaps a possibility of characterizing all or much of the reserve--this is through 5-10 minute point counts for birds. Still, we doubt that this is an advisable goal.

Core Zones as non-impacted "controls"--a risky assumption.--Use of core zones as non-impacted "controls" is risky because they are not necessarily unimpacted. In many cases, activities legally proscribed within core areas still take place there. Though it is still desirable to organize sampling, as described above, partly along the lines of management zones, any study needing a legitimate "control" area must endeavor to find truly effective controls, rather than assuming that official zonation alone can guarantee this result. Moreover, interspersion or at least proximity of control and impact areas is important, and sites should be matched for position along the prevalent topographic and forest-type continuum from bajos to hilltops.

C. Temporal organization of sampling

An important point to consider is whether sampling needs to take place throughout the year. To fully inventory the biota of any habitat or site, one would wish to sample throughout the year. This is true because long- and short-distance migration may occur in some species, as well as seasonal shifts in abundance, habitat use, and detectability. Such a need for year-round sampling imposes a serious constraint on the magnitude of a monitoring program, as many resources would have to be put into achieving year-round coverage for any single aspect of the program. It also would present formidable logistical problems during the rainy season, when access to many sites would be difficult and working conditions poor.

However, to serve the strict purpose of monitoring for ecological change, such a year-round sampling regime is not necessary. Rather, what is necessary is adherence to standardized methods within a set time of year, in order to derive a repeatable sampling, even though it does not represent the total year-round picture. Of course, there is always the danger that a certain kind of ecological change would only be manifest during one portion of the year and would go undetected if sampling were not conducted then; this risk is probably unavoidable.

Prior experience in the MBR has indicated the practicality of conducting as much sampling as possible during the dry season. At this time, access may be gained to areas that are inaccessible during the rainy season, and weather rarely poses limitations on field work. In contrast, during the rainy season, rain often interrupts field sampling. If sampling is restricted to the dry season, for example, from 1 February to 1 June, this gives four months, or about 17 weeks of sampling time per year. This restricted period places a great premium on adequate prior preparation and maximal efficiency of time use during the sampling season. Each proposed indicator must be evaluated with respect to the time of year when it is most revealing and practical to employ. Because of the many human-centered monitoring activities suggested here, which need not be restricted to the dry season, it may well be possible to occupy field monitoring crews year-round.

D. Spatial integration of data

It is desirable to spatially integrate inventory and monitoring data for the MBR, by geo-referencing all such data and use of a Geographic Information System (GIS). We recommend that a master GIS data base be maintained, presumably by CONAP. All data turned in to the master data base should be accompanied by accurate latitude and longitude references. Using the GIS, information on the biota and natural features of the reserve can be overlain with data on existing and impending threats to the reserve. This can highlight areas for special emphasis in patrol, enforcement, monitoring, and research.

E. Customizing vs standardization of methods

Though some customization to local conditions may be required, use of standardized methods, when available, will enhance the global value of the program by allowing maximal comparison with efforts carried out elsewhere.

F. Design of impact assessments

There apparently will be scope for many impact assessments in the MBR, for example, in documenting the effects of lumber extraction projects. The key things to bear in mind in design of such studies are the usual concerns of adequate replication, random sampling, etc. A traditional design is the "BACI" or before-after-treatment-control design. Several recent papers have suggested ways to improve the design of such studies (e.g., Schroeter et al. 1993, Thrush et al. 1994, Underwood 1994). Green (1979) has much relevant advice, as do Gauch (1982) and Hurlbert (1984). Underwood (1994) states that, while a single control (non-impacted) area is often used in such studies, this is generally not adequate, as it provides no true replication; wherever possible, multiple, truly replicate control sites should be utilized, and these should be interspersed, if possible, among treatment replicates (Hurlbert 1984). Interspersion will not always be possible, nor will true replication of "impact" units, as when a single contiguous site is to be logged. In this case, statistical inference may be limited, but one should still strive for adequate replication (or pseudoreplication) within sites, in order to be able to compare even a single impact site and one or more control sites.

G. The need for continual baseline sampling

Change over time as well as differences between sites can only be reliably detected if statistically distinguishable from natural levels of variability, both spatial and temporal. Hence sampling must be adequate in both spatial and temporal axes to allow adequate resolution of these sources of variation. It will of course take some time to quantify natural temporal variation, and climatic and weather variability on multi-year and multi-decadal scales implies that yearly monitoring of multiple control (nominally non-impacted) sites will be necessary for as long as the monitoring program continues.

H. Communities are dynamic--a reminder

One factor that complicates the characterization of baseline values is that the ecosystem or community in question may not be at a steady state even in the absence of human interference (Kelly and Harwell 1990). Or steady state may exist, but at a temporal or spatial scale exceeding that which is easily measured. For example, composition of the forest tree community may be determined by rare events such as periodic fires or blow-downs. In addition to designing a sampling regime that helps deal with such large-scale mosaic phenomena, we must simply do the best we can and keep these complications in mind. A more predictable kind of change is that due to succession. If we are monitoring a site subject to earlier natural or anthropogenic disturbance, we may expect to see the results of secondary succession, which should not be confused with the effects of other stressors.

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APPENDIX 1. EPA'S EMAP PROGRAM

The U.S. Environmental Protection Agency (EPA) has begun what must be among the most ambitious attempts anywhere to monitor sources and results of environmental degradation, primarily due to environmental pollutants. Design of this program, entitled the Environmental Monitoring and Assessment Program (EMAP), was begun in 1988, and its implementation began in 1990. The goals of EMAP are to provide a national baseline against which future changes in the condition of natural resources can be measured and the effectiveness of environmental policies can be evaluated. Specifically, it is hoped that this program will identify emerging environmental problems before they reach crisis proportions, and confirm whether EPA programs are truly maintaining or improving environmental quality (Potter 1993).

The following questions were formulated to guide the EMAP program:

1. What is the current extent of our ecological resources, and how are they distributed geographically?
2. What is the current status of the ecological condition of these resources?
3. What proportions of the resources are degrading or improving, in what regions, and at what rates?
4. Are these changes correlated with patterns and trends in environmental stresses?
5. Are adversely affected resources improving in response to control and mitigation programs?

Based on the above questions, the following EMAP objectives were defined:

1. Estimate the geographic coverage and extent of the Nation's ecological resources with known statistical confidence;

2. Estimate the current status of, and trends and changes in, selected indicators of the condition of the Nation's ecological resources on a regional basis with known statistical confidence;

3. Seek associations between selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources; and

4. Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.

The EMAP program monitors eight resource categories: arid ecosystems, agroecosystems, forests, inland surface waters, the Great Lakes, wetlands, estuaries, and landscapes.

"Forest Health Monitoring" component of EMAP

The component of the EMAP program potentially most relevant to monitoring of the MBR is the "Forest Health Monitoring" component. This component "was developed in response to increasing concern for the health of the nation's forests in light of the potential effects of atmospheric pollutants, global climate change, and a variety of insect, disease, and other stressors" (Alexander and Barnard 1994a). Objectives of this program are to (1) estimate with known confidence the current status, changes, and trends in selected indicators of forest ecosystem condition on a regional basis; (2) identify associations between changes of trends in indicators of forest ecosystem condition and indicators of natural and human-caused stressors, including changes in forest extent and distribution; (3) provide information on the health of the nation's forest ecosystems in annual statistical summaries and periodic interpretive reports for use in policy and management decisions; (4) identify mechanisms of ecosystem structure and function through long-term monitoring of ecosystem processes at intensive monitoring sites representing major forest ecosystems; (5) improve the effectiveness and efficiency of forest health monitoring through directed research; and (6) integrate forest health monitoring with other EMAP programs.

Indicators being used as of 1994 in this program were: (1) site condition, growth and regeneration; (2) crown condition classification; (3) damage and catastrophic mortality assessment; (4) photosynthetically active radiation; (5) vegetation structure (including floristic information); (6) bioindicator plants to reveal ground-level ozone damage; and (7) lichen communities. The above description makes clear that the emphasis of this program is on detection of the effects of air pollution and climate change. Mention is made of "insects, disease and other stressors", and apparently overt damage and crown condition are intended to be the primary indicators of these. Although floristic information is gathered as part of the vegetation structure and lichen community indicators, there is not a strong emphasis on determination of patterns of relative species abundance within communities. The focus is hence is not on biotic integrity *per se*, but clearly on the effects of air pollution. Since air pollution is not a high priority monitoring target in the MBR, none of the specific indicators being used in EMAP's forest health program appear to be transferrable to the MBR.

Procedures for selection and validation of indicators in the EMAP program

The following comments are based on Barber (1994). Prior to developing indicators, one must identify "assessment endpoints" which are formal expressions of the environmental values to be protected, partly through monitoring. EMAP uses three categories of environmental values--ecological structure and function, consumptive uses, and non-consumptive uses. Assessment questions are then framed, along the lines of "What proportion of resource R in region X is in condition C?" The information used to answer these questions are EMAP's "condition indicators". EMAP has classified indicators into condition indicators and stressor indicators. Condition indicators are any characteristic of the environment that provides quantitative information on the state of ecological resources and is conceptually tied to a value, i.e., assessment endpoint. Condition indicators include biotic ones (any characteristic of the environment that estimates the condition of a biological component of the resource), and abiotic ones (any characteristic of the environment that estimates the condition of physical or chemical components of the resource). Stressor indicators are those characteristics of the environment that are suspected to elicit a change in the condition of an ecological resource (Barber 1994). These condition indicators are equivalent to what are called "measurement endpoints" in the ecological risk assessment literature (e.g., Suter 1990).

EMAP employs a highly structured procedure in selecting indicators for nationwide use. Each topical group within EMAP goes through a process of indicator selection, evaluation, implementation, and periodic reevaluation. During indicator selection, EMAP groups (1) identify the environmental values of the resource in question, (2) formulate assessment questions that follow from these values, (3) identify the most likely stressors, (4) develop conceptual models depicting the resource's structure, function and likely response to stressors, and (5) select indicators for research and evaluation. During the following step, that of indicator evaluation, EMAP groups use best judgement, existing data, and pilot research and demonstration projects where necessary, in order to, for each proposed indicator: (1) evaluate logistics (2) characterize temporal and spatial variability, ecological responsiveness, and interpretability, (3) develop criteria as to acceptable and unacceptable indicator values, (4) prepare example statistical summaries and resource assessments, (5) determine necessary sampling density to estimate regional status, trends and associations with stressors, at specified confidence levels, and (6) select core indicators for implementation. Indicators are implemented only after thorough peer review. After implementation, indicators are periodically reevaluated via technical workshops for adequacy of performance, availability of improved methods, and the possible need for coverage of emerging issues.

Stressors that are considered by EMAP include: (1) reduction, loss and fragmentation of critical habitat, (2) reduced food resources due to pest control programs or other causes, (3) introduction of exotic species, (4) global warming, (5) alterations to regional hydrology, (6) chemical pollution of air, soil and water, (7) sedimentation and nutrient loading of waters, and (8) over-harvesting of biota.

Barber (1994) stresses the importance, during the process of indicator selection, of developing a conceptual model that describes a resource's structure and function and the ways it may be affected by stressors. Such models, according to Barber, should clearly demonstrate relationships between indicators, the values of interest, and anticipated stressors.

Indicator performance criteria

Table A1 lists criteria used by EMAP in evaluation of potential indicators. An indicator may not necessarily perform optimally in all respects, and one can question the validity or importance of some of these criteria. The indicator evaluation process entails evaluation of the indicator's conceptual soundness, operational feasibility, statistical behavior, and utility in resource assessment and in guiding policy and management decisions. Evaluation of operational feasibility involves questions such as defining the time of year measurements should be taken, all aspects of sampling methods, demands of equipment, personnel, sample identification and archiving, and data management and analysis.

Evaluation of statistical properties of indicators is probably the step that is most commonly ignored in designing monitoring programs. To evaluate these properties, preliminary sampling must be conducted. One must characterize the indicator's spatial variability (1) among concurrent samples from different locations within a sampling unit (e.g., local site), (2) among non-concurrent samples within the appropriate time window but from different sampling units within the region, and (3) among samples within the same time window in different regions. Similarly, one must characterize the indicator's temporal variability (1) among samples from the same sampling unit (i.e. site) during the same year and at the same locations but during different potential time periods for sampling, and (2) among samples within the same region and season but spanning a number of years. Finally, one must verify the indicator's response to stressors, and the variability thereof, by comparison of results at sites impacted to varying degrees by these stressors (i.e., validation of indicator response function). Based on results of these analyses of variability, one should determine the sample size and design necessary to achieve the desired degree of confidence in detecting a pre-determined degree of difference between sites or of change over time. It is essential to involve a professional statistician at this point.

Table A1. Indicator evaluation criteria used by EMAP (adapted from Barber 1994).

Criteria	**Explanation of criteria**
Essential criteria	
Unambiguously interpretable	Relates unambiguously to a recognized environmental value or assessment question; quantitatively conveys the same information for most resource sampling units within a regional resource class.
Ecologically responsive	Responds to stressors and to changes in resource condition across most pertinent habitats within a regional resource class.
Index period stability	Exhibits low measurement error and temporal variation during an index period.
Amenable to synoptic survey	Can be cost-effectively quantified by synoptic or automated monitoring.
High signal-to-noise ratio	Possesses sufficiently high signal strength (compared to natural variation) to allow detection of ecologically significant changes within a reasonable time frame.
Nominal-subnominal criteria	Possesses documented or identifiable thresholds or patterns of trends that identify the nominal or subnominal (i.e., acceptable or unacceptable) condition of the resource.
Minimal environmental impact	Sampling produces minimal environmental impact.
Desirable criteria	
Available method	Possesses a generally accepted and standardized measurement method that can be applied on a regional scale.
Historical record	Has existing historical data base or one can be generated from accessible data sources.
Retrospective	Relates to past conditions by way of restrospective analyses.
Anticipatory	Provides early warning of widespread changes in ecological condition or processes.
Cost effective	Has low incremental cost relative to information conveyed.
New information	Provides new information; does not duplicate data already collected.

Quality assurance within EMAP

Another desirable feature of the EMAP program which is very worthy of emulation in a monitoring program for the MBR is that it incorporates a quality assurance program in connection with its core monitoring activities. The quality assurance program is a highly formalized and standardized program designed to audit the way in which data are gathered, in order to document and ensure the quality and consistency of those data. This program (1) trains and certifies field personnel in use of sampling methods, (2) conducts post-training audits of field personnel within three weeks of the beginning of data collection, (3) conducts periodic field remeasurements throughout data collection to assess field personnel performance and control data quality, (4) debriefs field personnel after the field season to identify strengths and weaknesses of training, equipment, and procedures, (5) prepares periodic and annual quality assurance reports, and (6) integrates quality assurance results with corresponding data sets, data bases, reports and assessments, to document data quality and highlight significance to results and conclusions of monitoring (Cline et al. 1995).

APPENDIX 2. CATEGORIES OF SPECIES THAT MAY WARRANT SPECIAL CONSERVATION EFFORT, INCLUDING MONITORING

Noss (1990) lists five categories of species that may warrant special conservation effort, including intensive monitoring; we have added an additional category (economically important species):

(1) vulnerable species: those that are rare, persecuted, or otherwise prone to extinction

(2) economically important species: species that help sustain people in or near the reserve

(3) keystone species: pivotal species upon which the diversity of a large part of the community depends

(4) umbrella species: species with large area requirements, which, if given sufficient protected habitat area, will bring many other species under protection

(5) flagship species: popular, charismatic species that serve as rallying points for conservation efforts

(6) ecological indicators: species used as a surrogate for a larger group of species that have similar ecological requirements, or in other ways indicating something about ecological/environmental conditions

Indicator species were discussed earlier. Here we discuss the possible need for monitoring of the other five groups listed above.

1. Rare, endangered, and/or vulnerable species

We recommend that the following species be considered as rare, endangered, or vulnerable in the MBR, because of the factors listed below. Please note that we do *not* recommend all of these species for monitoring.

Species	Reasons for designation
Harpy Eagle	extreme rarity, probable disappearance from much of reserve
Scarlet Macaw	small, declining population; extirpated from much of northern Mesoamerica; persecution for pet trade; disappearance from parts of MBR
Jaguar	low population density; need for large areas of wild habitat; probably some hunting pressure
Puma	low population density; need for large areas of wild habitat; probably some hunting pressure
White-lipped Peccary	probable low population density; need for large areas of habitat; some hunting pressure
Tapir	low population density; need for large areas of habitat and for specific (wetland) habitat
Orange-breasted Falcon	extreme rarity; possibly declining population; rare nest sites; possibly impacted by increasing Black Vulture populations
Morelett's Crocodile	population reduced by hunting; specific habitat requirements (wetlands)
Jabirú	rarity; specific habitat requirements (wetlands)

No doubt additional species could be listed as being vulnerable or otherwise of special conservation interest in the MBR.

As stated earlier, we assume the objective of monitoring in the MBR is to help ensure the continued existence of the entire native biota of the reserve, within natural ranges of community composition, structure, and function. Hence, rare or vulnerable elements may merit monitoring simply to help guarantee their continued persistence in the reserve. In such a case, these species clearly are not being used as indicator species, but monitored for other reasons. For some species, rareness may be based on specialized habitat requirements, while for others it may be a consequence of large body size, high trophic position, or other factors, and endangerment may be due in part to direct exploitation by humans. Whatever the cause of rarity or endangerment, we believe that such species may at times merit monitoring for the sake of helping secure their populations, *even if their presence indicates nothing beyond their own presence*. In this case, the species are monitored, but they are *not* regarded as "indicator species". We emphasize this because there has existed much misunderstanding with respect to this in the past. To whit, using species as "indicators" in not the only legitimate reason to monitor them. The relative priority of monitoring rare, vulnerable or endangered species in an environment of limited funding, relative to that of monitoring indicators of biotic integrity, is a separate question.

2. Hunted (economically important) animal species

Economically important plant species were covered in an earlier section; here we list the main animals that are hunted for meat. According to data of Roling (1995) from Uaxactún, the animals most heavily hunted are the following (numbers given are estimated number taken by hunters of Uaxactún from August 1992 to November 1994):

Species	**Individuals taken**
Tepezcuintle (*Agouti paca*)	891
Cabro (*Mazama americana*)	518
Venado cola-blanca (*Odocoileus virg.*)	209
Jabalí (*Tayassu pecari*)	174
Armadillo (*Dasypus novemcinctus*)	162
Coche de monte (*Tayassu tajacu*)	84
Cereque (*Dasyprocta punctata*)	10
Pisote (*Nasua narica*)	8
Danto (*Tapirus bairdii*)	1
Faisán (*Crax rubra*)	796
Cojolita (*Penelope purpurascens*)	108
Pavo Petenero (*Agriocharis ocellata*)	42

4. "Umbrella" species

"Umbrella" species are those that require a large amount of space in order to maintain viable populations; as a consequence, protecting enough habitat space to provide for viable populations of such species generally provides space and habitat for most other members of the biotic community. Species mentioned as "umbrella species" are often ones of large body size, but in tropical forest, where a large proportion of all species present are rare species, potentially a large fraction of the biota could qualify for this title. For most tropical organisms, we have little knowledge of their densities or spatial requirements, making it difficult to use them as umbrella species. In the present case, the area to be protected is already defined--the Maya Biosphere Reserve. Hence, no additional justification is needed as to the area to be protected, and no species are proposed for monitoring solely on this basis.

5. "Flagship" species

The term "flagship" species refers to those that may serve as popular symbols--ones which the public recognizes and identifies with, and which thus may serve to rally people to the conservation cause. We feel that, within limits, and with adroit public awareness efforts, many species could serve this function. Though we doubt that in the MBR, any species merits monitoring solely based on its public popularity, some of the species that require monitoring on other grounds no doubt qualify also as flagship species--especially the Scarlet Macaw and perhaps the Jaguar.

APPENDIX 3. METHODS FOR MONITORING THE TERRESTRIAL BIRD COMMUNITY

Here we describe a bird monitoring scheme of two components--one which censuses some 90 species via 5-10 minute point counts, and another which uses one-hour, pre-dawn point counts and 2.5 hour canopy-emergent point counts to census the raptor, psittacine, and game bird communities. It is important to realize that our main goal is to infer changes in the ecological integrity of the forest biotic community from changes in the bird community, rather than to track changes in the populations of certain bird species (though we are interested in populations *per se* of hunted and rare species). This goal implies fundamentally different sampling goals than would be the case if we were tracking tendencies or viability of species populations.

a. Monitoring abundance versus demographic parameters

An initial choice must be made between intensive and extensive styles of monitoring. The most intensive approach to monitoring is exemplified by the "constant-effort mist netting" approach, as applied, for example in the "MAPS" program (Monitoring Avian Productivity and Survival [DeSante et al. 1993]). In this approach, a limited number of sites are studied. At each site, several mist nets are set in the same place each year for a few weeks during the breeding season, and intensive mist-netting, banding, and recapture is directed at several species for which adequate captures can be made. This approach yields data on post-fledging and adult survivorship, and on annual nesting productivity. These demographic parameters are highly useful, for example, in analyzing the regional population status and trend of a species (if enough such sites can be operated). However, as indicated above, our goal is not to track the population trends of certain species, but rather, to use these suites of bird species to make inferences about the biotic integrity of the forest community as a whole. Hence, we are more interested in characterizing the bird community at many sites, and at the same sites over time, than in documenting demographic parameters for any one species.

Even in efforts to characterize habitat quality, many researchers have stressed the need to gather data on reproduction and survival, rather than simply information on avian abundanc in the habitats of interest. This can be important because the mere number of individuals present may not reveal the species' status in that habitat or the value of the habitat to the species. A habitat which is inferior in quality could, for example, be well-stocked with that species if socially subordinate individuals, excluded from better habitat, were crowded together there. Or, the species may be abundant in the habitat, but may have poor survival and/or reproduction there. Recently, increasing recognition has been given to the notion that certain habitats may serve as population "sinks"; a species may be present in them, but without adequate reproduction for the population to be self-sustaining. Populations in such "sink" habitats can be maintained through emigration of individuals produced in better sites, which serve as "source" habitats of colonists.

Though the above cautions about source and sink habitats are no doubt valid, indices of species abundance at different sites and habitats is still a useful quantity to use in initial evaluations, and is far easier to gather than information on reproduction and survival. Hence, we suggest a focus on obtaining indices of species abundance at different sites and habitats, and in particular, on detecting changes in these indices within sites over time.

Another reason to shy away from the intensive methods described above, is that, with limited resources for monitoring, a given unit of bird monitoring effort can be allocated either intensively to a very few sites (e.g. constant-effort mist-netting sites), or more extensively over a broader region. Wilcove and Terborgh (1984) postulate that bird population declines may manifest themselves in any of five ways as described in Table A3. Study of Table A3 reveals that some of the possible manifestations of avian population decline would not necessarily be detected by monitoring at one or a few sites or in one habitat type, but are best detected by more superficial work (even presence-absence data) at a multitude of sites and a variety of habitats, including suboptimal habitat. This is a further reason why less intensive monitoring at many sites can be more useful than very detailed monitoring at one or a few sites.

Furthermore, one recent paper claims that even detailed data on survival and reproduction are not usually adequate to distinguish between source and sink habitats anyway (Watkinson and Sutherland 1995). In this case, great effort to elucidate reproductive and survival rates at one or a few sites would be a case of mis-placed precision--such efforts might produce numbers of questionable value at very few sites, while more superficial efforts such as point counts at a great many sites would have provided at least an idea of the species' abundance, regionally, and in different habitats.

Table A3. Possible manifestations of population decline in birds, after Wilcove and Terborgh (1984).

		Geographical Response	
Local Response		retract from periphery of range	maintain full geographic range
	maintain normal densities in all habitats	Type I decline	no population decline
	retract from marginal habitats	Type II decline	Type IV decline
	reduced densities in marginal and optimal habitat	Type III decline	Type V decline

However, even within the realm of point counts, relatively intensive (geographically focused) and extensive (with greater geographical coverage) approaches are possible. For example, point counts may be organized into routes of about 12 counts, 200 m apart along trails through the forest; one such route is censused per censuser or census team per morning. In contrast, one can achieve greater geographical coverage by doing briefer counts at intervals along a route driven by car, which achieves greater geographical coverage per morning. The North American Breeding Bird Survey uses fifty, 3-minute census stops, each 0.5 mile (0.8 km) apart along a 25-mile driven route; the census is begun 1/2 hour before sunrise. It seems that the latter--a system of on-road, brief point counts, with at least 30 accomplished per morning, may be a good method for areas where human encroachment and land use patterns are rapidly changing the face of the land--e.g., in areas of the buffer zone and other portions of the reserve where immigration is proceeding rapidly. In contrast, the former approach--of fewer, but longer and more thorough point counts, not restricted to roads--may be better for creating a more sensitive portrait of subtle ecological conditions in areas that are more pristine and not changing so rapidly--ie. core zones and other areas where gross anthropogenic change is proceeding less rapidly.

b. Monitoring a large subset of the bird community via morning point counts conducted from the ground

We propose a bird monitoring scheme resembling the U.S.'s "Breeding Bird Survey". This program uses point counts to document abundance patterns of a large list of bird species. Based on our experience conducting hundreds of avian point counts in the MBR, we feel such an approach is highly recommended for the MBR, and for eventual extension, perhaps providing an avian monitoring program for the entire republic.

We recommend:

1. Use 5-10 minute point counts.

Further experimentation should be conducted to determine the most efficient duration for point counts in the MBR. In 1993 and 1994, we used 10 minute point counts in the MBR, which worked very well. However, it is possible that a shorter count could yield greater efficiency. Based on our experience in the MBR, we discourage the use of counts shorter than five minutes, even though three minute counts are used in the North American Breeding Bird Survey. We feel that the greater avian diversity in Petén than in the U.S. and Canada necessitates a longer count duration in order to record all the species calling. We feel that the optimum count length will prove to be between five and ten minutes. Several papers in Ralph et al. (1995) discuss the optimal duration of counts, which is partly a function of travel time between points. If further experimentation is not conducted, we recommend use of 10-minute counts.

2. Use a point count radius of 100 m.

Our rationale here is the following. We will not claim to be able to detect all calling individuals of all species to a radius of 100 m. However, such a claim is not necessary, as we do not propose to calculate density from count results; hence it is not necessary to count all species effectively over the entire count radius. Rather, we will use results as an index of relative abundance. Individuals thought to be greater than 100 m from the point will also be recorded, but coded as such; results can then be analyzed with or without those individuals included. In either case, this approach closely resembles an unlimited-radius approach, as the detectability distance will vary by species, and we make no attempt to adjust for this. Two alternate approaches exist, and have shortcomings as follows. First, one may use a short, fixed radius, say 30 or 50 m. However, this greatly diminishes the number of individuals included in counts, which makes for inefficiency, i.e., low data capture per unit effort. Furthermore, it is difficult to accurately estimate distances of bird calls in the Petén forest. Use of 100 m, which is a large radius, makes it an easy judgement call as to which bird calls are within the radius; most birds detected are within this radius. In contrast, making such a judgement at the 30 or 50 m radius we found to be much more difficult. In the other method, one estimates distances to each individual detected, in order to generate a detectability constant for each species, which is then used in estimating density. We feel that the poor accuracy inevitable in all distance estimations in these censuses in tropical forest leads to an unacceptable propagation of errors throughout the calculations used to estimate density; we feel that this method creates an inappropriate impression of precision when in fact accuracy may be far off the mark. In contrast, the method we propose is, we feel, the simplest way of employing point count data in this environment.

3. Counts should be organized into routes of 10-30 counts; each route is to be censused during a single morning, between prescribed hours. We suggest that counts begin 30 minutes before official sunrise and end 2.5 hours after sunrise; experimentation should be conducted before a final standard is selected. It will be important to keep in mind that the day heats up more quickly in open habitats, and hence bird activity may drop off there more quickly than in the forest. Counts should not be conducted after activity begins to markedly wane.

4. Points should be spaced at least 200 m apart, in known habitat "type", which is documented in a simple fashion for each point.

5. Some routes can be done by automobile, while others will be travelled on foot or by boat.

6. Intensive observer training should be conducted, to help ensure consistency and reliability of results.

7. Each route of counts should be done a defined number of times per year, and during a prescribed season, under a prescribed range of acceptable weather conditions. Counts should be suspended if rain, wind, cicadas, brown jays, or howler monkeys make listening conditions unacceptable; often conditions will again become acceptable after a few minute respite.

8. Advice as to statistical analyses of point count data may be found in Ralph and Scott (1981), Ralph et al. (1995), Sauer and Droege (1990), and in numerous other recent journal articles.

9. This approach can be used in any portion of the reserve or surrounding areas which is accessible to humans, and can be used in a variety of habitats, possibly with some modifications for different habitats.

10. The dates during which counts are to be conducted must be defined and kept standarized from year to year. It is important to recognize that bird species differ in frequency of calling, and hence in detectability, throughout the season, even during the dry season period we recommend for censusing. These patterns of seasonal change need to be quantified and their implications for analyses contemplated.

11. An important consideration is whether to conduct multiple censuses at any given point during the same year, rather than putting that sample effort into additional points. This decision is discussed by Barker et al. (1993), Link et al. (1994), and various papers in Ralph et al. (1995). Sampling more than three times within a comparison unit (e.g., per year) is rarely warranted. In general, we recommend that each point be sampled either once or twice per year.

c. Monitoring of psittacines, raptors, and columbids from canopy-emergent point counts and pre-dawn listening counts.

1. Detailed methods for these censuses are given by Whitacre et al. (1992).

2. The canopy-emergent count is a point count beginning one half hour after official sunrise. We have used count durations of 2.5 to 4 hours. We recommend further consultation with D. Whitacre before finalizing a choice of count

duration.

3. The method requires a clear view 120 degrees in width over the forest canopy, extending to a radius of one kilometer from the lookout point.

4. In open areas or along rivers, these counts can be conducted from the ground or from a boat; in areas of continuous forest, they require censusing from the crown of a canopy-emergent tree, cliff, or maya temple.

5. Data are recorded during each 5-minute period; the number of distinct individuals detected for each species is recorded for each 5-minute interval. There are various ways to analyze the resulting data. One could, for example, analyze the number of five-minute periods during which the species was recorded. However, we have primarily used the following approach; for each species, use the largest number of individuals detected during any five-minute period. This single number is used to represent the results of the census for that species.

6. Details of methods and sample data sheets for this method will be provided on request by the author.

7. A pre-dawn listening count is also conducted at the same site on each sampling date. This count is done from the ground. We have conducted this as a one-hour count beginning one hour prior to official sunrise. Data are recorded during each 5-minute period; the number of distinct individuals detected for each species is recorded for each 5-minute interval. Data from the pre-dawn count and the canopy-emergent count can be combined into the same analysis; for species detected by both methods, one must decide which method most adequately samples that species, and use results of that method for all comparisons.

Though we have widely used one-hour pre-dawn counts, one could accomplish a few to several counts of shorter duration during that hour, for example, four ten-minute counts at intervals of 200 m. A drawback of this approach, however, is that temporal patterns of calling change rapidly during this hour, as light intensity reaches calling thresholds of various species in turn. Hence, counts conducted an hour prior to sunrise are not comparable with those conducted 30 or 45 minutes later. Hence, it is probably best to continue using our one-hour count. It would be worth analyzing our existing data in order to see how much information would be sacrificed by moving to a shorter count, say a half-hour count beginning 30 minutes before sunrise; conceivably, little information would be lost by doing so.

d. Replicability of bird censuses over a multi-year horizon

One challenge for any monitoring efforts, which by definiton are conducted over many years, is to guarantee comparability of data across years. One must not only prevent "drift" in methods over time, but also guarantee that data quality are high and consistent throughout the time span, which could ultimately be decades or centuries. Here we address specifically those challenges presented by bird sampling, but the same considerations should be contemplated throughout the monitoring program.

In bird sampling, one must be concerned with replicability and documentation of bird detection ability, bird identification accuracy, and census protocols. A key prerequisite is to conduct adequate training in methods, detection, and identification prior to beginning "real" censuses. This requires practice with a large collection of bird-sound recordings and adequate practice in the field, along with highly experienced individuals to serve as trainers. However, training alone is not adequate; one must also create a permanent record which, for each individual taking part in censusing, documents his/her ability to detect and identify birds; this should be done, at a minimum, at the outset, mid-season, and end of each sampling season. We recommend the following:

1. Periodically make voucher tape recordings during censuses; do this several times during each censusing season for each observer, and in all relevant habitats. Compare voucher recordings to census results, conduct additional training as necessary, and maintain voucher recordings, permanently archived. Another alternative would be to tape-record bird calls throughout all censuses. However, we do not recommend the latter, because: (a) it either requires an additional person or infringes on the ability of the primary censuser to accurately census, and (b) it results in a large number of tape-recordings which must be archived, and (c) to actually go through these recordings and compare them to written census results requires a monumental effort.

2. Periodically test censusers, by having a highly experienced person who can serve as a maximally accurate "benchmark", conduct censuses along with the person in question; do this in a "blind" fashion, i.e., without consultation; compare results afterward, record these permanently, and then conduct training and practice as needed in order to eliminate or minimize discrepancies. Extensive practice censuses and testing should be conducted just prior to the beginning of the censusing season; all results should be assessed and permanently archived.

3. At the outset of censusing, make a list of the species being included in census efforts, and which all censusers nominally are capable of identifying. This list need not include all bird species occurring in the area, but ideally should include the great majority. Tabulate also a list of the different vocalizations recognized for each species.

The importance of adequate training and experience in species detection and identification cannot be overstressed. Many studies have revealed differences between observers in census results, arising partly from differences in experience and skill. Kendall et al. (1996) recently showed that results of North American Breeding Bird Survey (BBS) differ depending on whether data from individuals' first censuses are included. In their first censuses, observers detected fewer birds of many species. While such initial censuses can be omitted during the data analysis stage, it is most efficient to ensure that adequate identification practice and verification with experienced instructors, and adequate practice in actually conducting point counts, are acquired before serious point counts are begun. Differences in hearing ability can also affect results, especially for species with very high-pitched, low-pitched, or quiet calls.

d. Data analysis.--Some potential methods of analysis are mentioned in Appendix 16.

APPENDIX 4. INDICATOR PROPERTIES OF THE TERRESTRIAL BIRD COMMUNITY OF TIKAL NATIONAL PARK

Shown here are ordination diagrams for eight bird species representing eight patterns of habitat affinity we recognized among 90 species subjected to such ordination (the ordination shown here included only 60 species).

All eight panels depict the same ordination, which used Detrended Correspondence Analysis (DCA). The arrangement of points is the same in each panel; these are the arrangements of samples (mean of two censuses) in ordination space. The occurrence (and abundance, large circles indicating multiple individuals per census) of each species in each sample is indicated in each species panel. The predominant environmental axis is from tall, closed-canopy, upland forest at the right to young (3-year old) second growth at the lower left, with "bajo" forest protruding to the upper left.

The third page of this appendix lists the tentative allocation of 90 bird species to these "habitat response types". Finer differences are detectable by inspecting species centroids (not shown) and each species panel equivalent to those presented.

Results presented here are based on Whitacre et al. (1995).

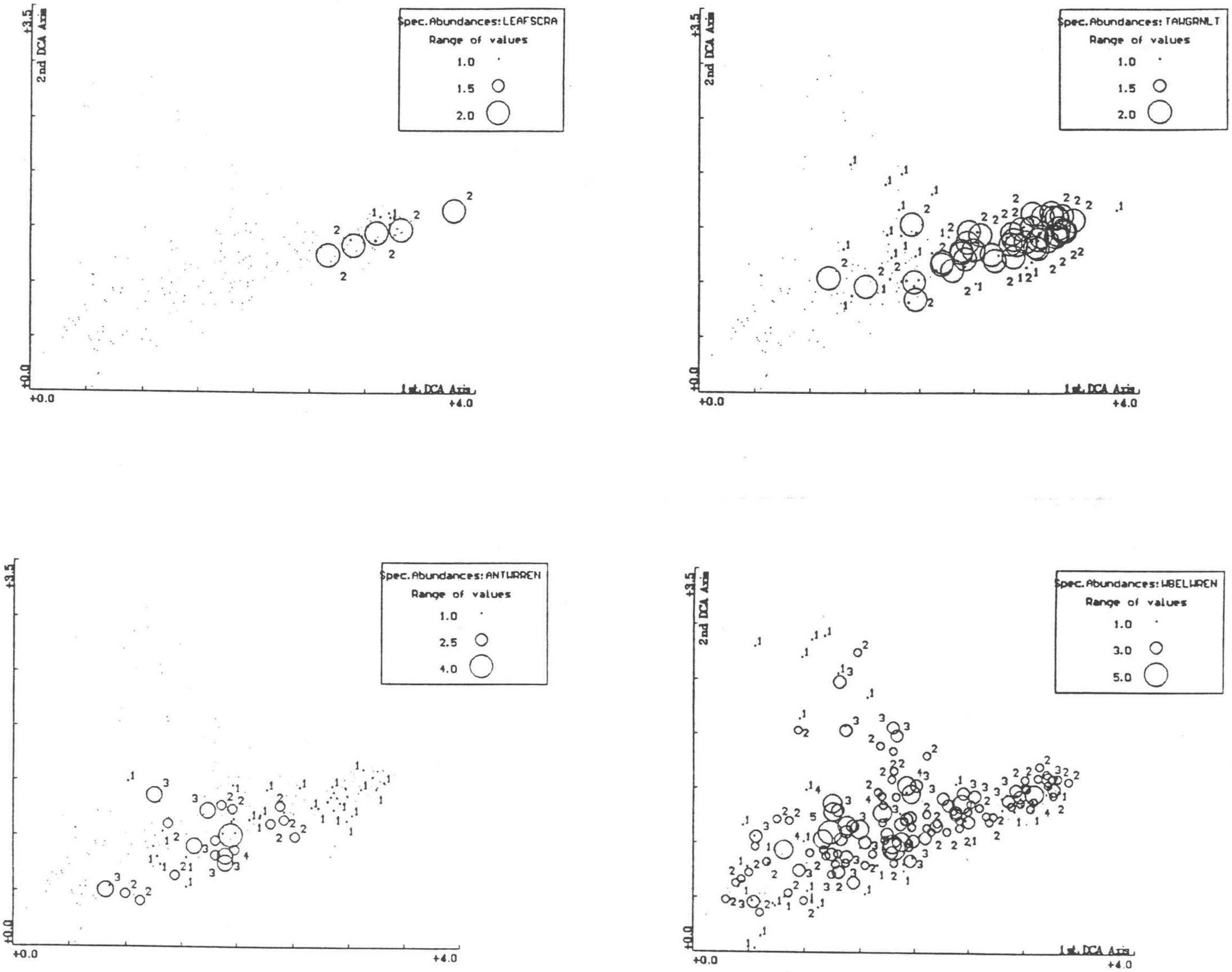

Figure 2 A. Ordination diagrams for species representing four of eight patterns of habitat affinity tentatively recognized among 60 species tested. *Leafscra* = Scaly-throated Leaftosser, representing "mature upland forest 'obligates'"; *Tawgrnlt* = Tawny-crowned Greenlet, representing "tall forest species"; *Antwren* = Dot-winged Antwren, representing "intermediate forest species"; *Wbelwren* = White-bellied Wren, representing "forest generalists". Descriptions of these habitat response patterns are given in text. Axes are first and second axis of Detrended Correspondence Analysis performed on species occurrence data for 60 bird species with significant habitat effects in Kruskal-Wallis tests comparing 11 habitats.

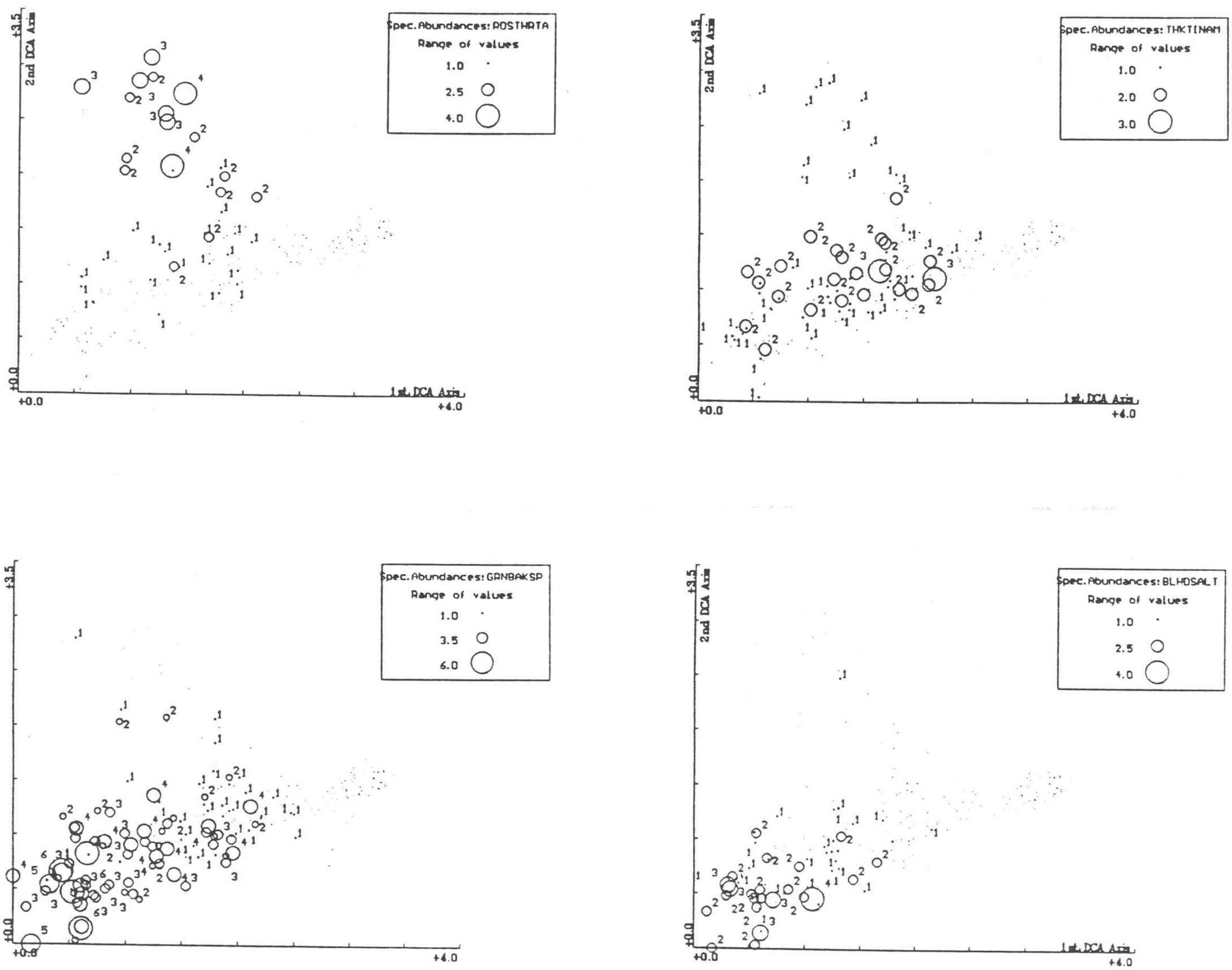

Figure 2 B. Ordination diagrams for species representing four of eight patterns of habitat affinity tentatively recognized among 60 species tested. *Rosthrta* = Rose-throated Tanager, representing "bajo specialists"; *Thktinam* = Thicket Tinamou, representing "second-growth/bajo species"; *Grnbaksp* = Green-backed Sparrow, representing "second-growth species"; *Blhdsalt* = Black-headed Saltator, representing "young second-growth species". Descriptions of these habitat response patterns are given in text. Axes are first and second axis of Detrended Correspondence Analysis performed on species occurrence data for 60 bird species with significant habitat effects in Kruskal-Wallis tests comparing 11 habitats.

Tentative group membership for eight "habitat response types" shown by 90 bird species studied at Tikal, Petén, Guatemala.

Group One
"Mature upland forest 'obligates'" (21 species)

Lanio aurantius
Sclerurus guatemalensis
Mionectes oleagineus
Tinamus major
Trogon collaris
Vireolanius pulchellus
Leptopogon amaurocephalus
Pipra mentalis
Dysithamnus mentalis
Crax rubra
Crypturellus boucardi
Rhytipterna holerythra
Hylomanes momotula
Euphonia gouldi
Dendrocincla anabatina
Basileuterus culicivorus
Trogon massena
Campephilus guatemalensis
Columba nigrirostris
Micrastur ruficollis
Geotrygon montana

Group Two
"Mature forest species"
(14 species)

Ramphastos sulfuratus
Amazona farinosa
Hylphilus ochraceiceps
Schiffornis turdinus
Platyrinchus cancrominus
Henicorhina leucosticta
Contopus virens
Habia rubica
Xiphorhynchus flavigaster
Hylophilus decurtatus
Sittasomus griseicapillus
Celeus castaneus
Dendrocincla homochroa
Caryothraustes poliogaster

Group Three
"Intermediate forest species"
(2 species)

Microrhopias quixensis
Polioptila plumbea

Group Four
"Forest generalists"
(25 species)

Psarocolius montezuma
Tolmomyias sulphurescens
Amazona autumnalis
Thryothorus maculipectus
Oncostoma cinereigulare
Rhampocaenus melanurus
Uropsila leucogastra
Leptotila plumbeiceps
Melanerpes aurifrons
Cyanocorax morio
Columba speciosa
Momotus momota
Trogon violacea
Pteroglossus torquatus
Ornithion semiflavum
Trogon melanocephalus
Attila spadiceus
Habia fuscicauda
Euphonia hirundinacea
Amazilia candida
Myiopagis viridicata
Cyanocompsa parellina
Piaya cayana
Formicarius analis
Myiarchus tuberculifer

Group Five
"Bajo specialists"
(4 species)

Piranga roseogularis
Granatellus sallaei
Myiarchus yucatanicus
Vireo pallens

Group Six
"2nd-growth/bajo species"
(3 species)

Crypturellus cinnamomeus
Claravis pretiosa
Thryothorus ludovicianus

Group Seven
"2nd-growth Species"
(10 species)

Cyanocorax yncas
Crypturellus soui
Dumetella carolinensis
Cyanocompsa cyanoides
Myiodynastes luteiventris
Amazilia tzacatl
Arremonops chloronotus
Turdus grayi
Vireo flavoviridis
Dives dives

Group Eight
"Young 2nd-growth species"
(9 species)

Leptotila verreauxi
Saltator coerulescens
Columba flavirostris
Ortalis vetula
Myiarchus tyrannulus
Saltator atriceps
Amblycercus holosericeus
Thamnophilus doliatus
Sporophila torqueola

APPENDIX 5. Potential avian census routes in the MBR

The intent of this appendix is simply to give an idea of how sampling of bird communities (and other indicators) could be spatially allocated.

1. Yaxhá area: from Ixlu to Melchor, and to north.

car routes - 2 or more routes along main road; 1 or more routes N of Melchor on secondary roads.

walking routes - routes between Xaxha and Nakum censused by The Peregrine Fund in 1995.

2. Tikal area: From Ixlu to Uaxactun.

car routes - 1 to 3 routes along main road between Ixlu and Tikal; 1 route in Tikal, from S boundary to park center; 1 route in Tikal from park center to N boundary; 1 route from N boundary of Tikal to Uaxactun.

walking routes - 1 route from Caoba airstrip, NE along Rio Azul road; several other routes possible in vicinity of El Caoba; within Tikal, any number of routes possible along trails and transects well-distributed from S park boundary to N park boundary; N of Tikal, routes possible along various logging roads; N of Uaxactun, along various logging roads; W of Uaxactun, along logging road to Zotz and San Miguel. 214 point counts censused by Peregrine Fund here in 1994, from Ixlu to Uaxactun could be used.

3. Dos Lagunas/Rio Azul area.

car routes - various routes possible along main roads.

walking routes - any number possible along main and other roads.

4. San Miguel/Carmelita area: from San Jose to Carmelita; eastern half of Rio San Pedro.

car routes - several routes possible along road between San Jose and Carmelita; one along road from Cruce Dos Aguadas to Zotz; one along same road, from Zotz toward Uaxactun.

walking routes - any number possible along logging roads in from main road between San Jose and Carmelita; routes within Biotopo Zotz and on road from Zotz toward Uaxactun; one or more each at El Peru; Peñon de Buena Vista, and Estacion Biologica Las Guacamayas.

water-born routes - One or more on upper Rio San Pedro; possibly one on Rio Chocop and other tributaries.

5. Laguna Perdida area: roads to E and N of Laguna Perdida, from Laguna Gloria area to Rio Tamaris, from here westward toward La Reina, Laguna La Gloria west along main road, and N to Arroyo Peje Lagarto.

car routes - Several possible along main and secondary roads throughout; route along oleoducto?

walking routes - Several possible along logging roads.

6. Western buffer zone: buffer zone from junction of Arroyo Peje Lagarto road W and N to boundaries of P N Sierra del Lacandon and Rio San Pedro.

car routes - Several possible along main and secondary roads.

walking routes - Several possible along secondary and tertiary roads and logging roads, trails.

7. Parque Nacional Sierra del Lacandon: within park boundaries, from Naranjo road to Rio Usumacinta.

car routes - One possible on road to Bethel; any others?

walking routes - mostly walking routes, on trails and logging roads throughout southern and eastern fringes of park.

water-borne routes - Rio Usumacinta.

8. Parque Nacional Laguna del Tigre: as per official park boundaries.

car routes - 1-3 possible along oil-field roads.

walking routes - Several possible along oil field roads and trails.

water-borne routes - Rio Escondido as censused by Peregrine Fund in 1991; up Rio San Pedro from Naranjo; others?

APPENDIX 6. METHODS FOR MONITORING MEDIUM-TO-LARGE TERRESTRIAL MAMMALS

Our goal in monitoring mammals should be to monitor for changes in the mammal community at given sites over time. We should focus on detecting temporal changes in indices of abundance of individual species and of the composition and relative species abundance (i.e. structure) of the community of medium-sized and large mammals. In addition to the use of questionnaires of local residents and recording observations during resource guard patrol activities, we recommend using one of the following three approaches. Although these approaches are listed here in order of decreasing desirability, any one of the three would be adequate if carefully developed.

After this section was written, we received a virtual bible of carnivore detection methods (Zielinski and Kucera 1995), which should be carefully studied, as it may alter some of the conclusions offered below; in particular, it reviews other automatic camera systems and gives great detail about the use of these and track plates.

Population density and home range size of jaguars

Before describing possible sampling methods, it is useful to review what is known about population density and home range size of jaguars. Though the sampling methods proposed here are aimed at monitoring several species of medium-to-large, terrestrial mammals, an emphasis on jaguars and pumas is probably advisable, for reasons stated earlier. In focusing here on jaguars, we do not mean to imply that monitoring them is more important than monitoring pumas. However, we are not aware of any detailed studies of pumas in tropical forest habitats.

Schaller and Crawshaw (1980) found that female jaguars in Brazil ranged over at least 25-38 sq km, and that males ranged over more than twice this area. As is typical of solitary cat species, they found that home ranges of adult females overlapped broadly, while the larger ranges of males contained several female ranges, but were probably nearly mutually exclusive between adult males, though with some trespass by neighbors and passage of transients. Population density in this Brazilian study was one jaguar per 22.5-25 sq km, though perhaps as high as one jaguar per 12.5 sq km of the habitat most used in one area. Some jaguars in Brazil had home ranges as much as 16 km across. One puma radio-collared at the same Brazil study site used an area of 32 sq km over a two-month period; this perhaps suggests that pumas there used a smaller home range than did jaguars, though the sample size is obviously inadequate to be certain of this; at any rate, it was in the same order of magnitude as that of jaguars at that site.

In Belize, male jaguars maintained overlapping home ranges of 28-40 sq km, while females utilized areas of at least 10 sq km within the ranges of individual males (Rabinowitz and Nottingham 1986). Males often remained in small areas of 2.5 sq km for up to two weeks, then shifting overnight to another portion of their range. At least one puma moved within the ranges of several male jaguars. There was evidence of mutual avoidance by jaguars and by jaguars and puma, as well as evidence of passive territory maintenance (i.e., by marking). In another study in Brazil, Crawhaw and Quigley (1991) found that six jaguars (two males and four females) had a mean home range size of 142 sq km. Mean home range during the dry season was 54.3 sq km and in the wet season was 12.8 sq km. Mean overlap between home ranges of four females was 42 %.

To summarize, jaguars in one of the Brazil studies had home ranges twice the size of those in Belize, while in the second Brazil study, home ranges were three times as large as in the first Brazil study and six times as large as those in Belize. There are several possible explanations for these differences. First, jaguars in the Brazilian study area are about twice as large as those in Belize, probably indicating greater food demands (Crawshaw and Quigley 1991). Second, in Belize, jaguars were preying mainly on small prey such as armadillos which were abundant and evenly distributed over the landscape, allowing use of a smaller hunting range by the cats. Finally, and probably accounting for much of the difference, the Brazilian sites, in the Pantanal wetland, had large areas that were seasonally flooded. Densities of both prey and jaguars were probably limited by the amount of dry ground available during the wet season.

Radio-collared jaguars in the first Brazilian study (Schaller and Crawshaw 1980) showed three general types of movement: (1) at times they remained at a kill for 2-3 days, (2) they sometimes roamed back and forth within a square km or two for a few days, and (3) they sometimes crossed much of their homerange in the space of a few days, with little meandering. Linear distances between radio locations on consecutive days varied from 500 m or less to 4 km, indicating a degree of movement similar to that for female tigers, leopards, and puma. However,this measure may often underestimate the amount of travel the cat actually did; in the case of a 4 km day-to-day movement, the cat actually covered at least 11 km, sometimes backtracking.

Proposed sampling methods for medium-to-large terrestrial mammals

1. Trail Timer infra-red triggered cameras

This is the method we recommend most highly. It is explained in Kawanishi (1995); this unpublished thesis is available from Dr. Howard Quigley at Hornocker Wildlife Institute, University of Idaho, P.O. Box 3246, Moscow, ID 83843. The Trail Timer camera is available from Trail Timer, P.O. Box 19722, St. Paul, Minnesota 55119, FAX (612) 439-7299.

This camera unit costs $175, and consists of an infra-red event sensor connected by an electric cable to a camera system that houses and mechanically triggers an inexpensive automatic camera with built-in flash. An internal clock allows the date and time of up to five triggering events to be stored (for $65 more, a unit recording up to 500 detection events is available). A 1-minute delay in the sensor ensures that the same animal is not repeatedly sensed and photographed during one passage near the unit. Kawanishi (1995) recommended use of a high-speed print film (e.g. 400 ASA), which can be black and white and hence fairly economical.

Kawanishi (1995) used this unit at Tikal with great success, to survey mammal populations. She mounted the unit on a tree, aimed across a lightly-used forest trail, so that passing mammals (or other animals of substantial size) would interrupt the infrared sensor beam, triggering the camera. She used no attractants, which is a great advantage of this system; by not using any bait or attractant, one can obtain a largely unbiassed assay of the animals within a certain size range that use the trail in question.

Some other commercially available remote-triggered camera units have seen substantial problems in field use. For example, the Trailmaster brand camera, while costing much more ($540), in one study experienced a high rate of spurious triggering events that did not result in animal photographs (Rice et al. 1995). Though this may partly be compensated by additional training, experimentation and practice (Rice et al. 1995), Kawanishi (1995) had far better results with the cheaper Trail Timer unit, and without experimentation and training. Hence the advantage of the Trail Timer over other commercially available, similar units at this time may be compelling. The high success rate experienced by Kawanishi (1995) is probably in no small part due to the fact that she positioned cameras so that the infrared beam was interrupted by a large tree at the 4.6 m limit of effective photograph ability of her units (as determined by flash brilliance and film ASA). Because the infrared sensor is effective out to a distance of 20 m, failure to truncate the beam in this fashion may have generated triggering events that resulted in no animals being photographed. Other hints for effective set-up are given by Kawanishi (1995).

Advantages of this system mentioned by Kawanishi (1995) include:

1. Reliability and low frequency of spurious triggering events.
2. Moderate cost.
3. Disturbance to wildlife is minimal.
4. Batteries and 36-exposure film would be adequate for about a month of operation without replacement; this would allow many cameras to be operated by a single investigator.
5. Can detect any species in the appropriate size range, by day or night.
6. Provides irrefutable evidence of presence, and positive species identification.
7. It is free of biasses associated with use of attractants and observer ability.
8. Can be rigorously standardized over a wide geographical area, over time, and between investigators.
9. By use of built-in timers, allows documentation of time of day and periodicity of activity.
10. If individual recognition is possible, and with adequate sampling intensity, could allow estimation of population density.

The primary disadvantages of this system are: (1) vandalism, and (2) moderately high initial cost. In reality, the cost over the life of a project may be low compared to alternatives that utilize more manpower, especially considering the high quality of data collected by this method. This leaves vandalism as the main drawback. Vandalism problems are to be expected mainly in areas where people commonly move through the forest, i.e., areas heavily visited by hunters, xateros, huecheros, and chicleros. To a certain extent, these problems can be minimized. When sampling in truly remote areas, there should be a much lower incidence of such problems. And when operating near villages, no doubt these problems can be minimized by explaining to local people beforehand the project and its value to them, showing them the camera rigs to be used, and asking for their cooperation in leaving the cameras undisturbed.

Regardless, some vandalism and loss of cameras and data will occur. Thus, a realistic cost estimate must allow for camera replacement, in addition to that occasioned by wear and tear. Furthermore, in order to maintain the resultant data close to that intended by the study design, cameras should no doubt be checked with some frequency, for example, weekly. This would allow fairly prompt replacement of stolen or tampered cameras, perhaps at alternate sites. In contrast, if cameras are checked only once monthly, one may lose the entire month of data for each camera that turns up damaged or missing.

Sampling efficacy

During three months (March-May) at Tikal, Kawanishi (1995) obtained 80 identifiable wildlife photographs in 574.5 camera-nights (she defined a camera-night as a night with two effective cameras along a 500 m transect, so this could also be interpreted as 1149 camera-nights.) This amounts to either 13.9 % or 7.0 % success, depending on the definition of a camera-night used. These 80 photos represented 18 mammal species and four bird species. Carnivores were quite well represented in the photos, with six detections each of ocelot and margay, five of puma, and one of jaguar. When these detection rates for cats are compared to the single paca and six of agouti detections made during the same effort, it appears that this method sampled cats more effectively than it did these large rodents. Kawanishi (1995) points out that cats are known to use man-made and other trails for travel and hunting, and speculates that potential prey species may avoid trails for such reasons.

This apparent bias is not a problem for this method, as we propose that cats be a primary focus of our sampling. Even though ungulates and rodents may be under-sampled by this method relative to carnivores, the method will nonetheless provide data on ungulates and rodents in a systematic fashion as well. And while this method may not sample the entire terrestrial medium-to-large-bodied mammal community in a bias-free fashion, it should nonetheless, when conducted at adequate intensity and sufficient repetition over time, reveal any marked changes in the relative abundance of the members of the sampled mammal community. This is a desirable attribute, as changes in composition of the mammal community are a predicted result of changes in abundance of top predators such as puma and jaguar. If the populations of the latter are affected by (1) hunting, (2) disease, (3) habitat alteration, (4) habitat fragmentation, or any other factor, then any marked resultant changes in the composition and structure of the community of medium-to-large mammals should be revealed by this sampling method.

Furthermore, as mentioned by Kawanishi (1995), use of cameras along trails could be supplemented by camera use in other contexts which may have different sampling biasses and hence provide a complementary view of the mammal community. She suggests use of cameras at salt licks, water holes, along forest edges, and ridge tops.

Nature of resultant data

Data will be in the form of number of photographs of each species, per effective camera-night, i.e., detections per camera night. Such data can be analyzed via a number of standard statistical tests.

Experimental design

The main questions revolve around determining the optimal number and spacing of cameras, and the time interval over which they are left in place. Desirable values for these variables may hinge on factors such as cost, availability of human resources, transportation, etc. Here we will first suggest standards that should be adhered to under any design, and second, will suggest potential designs.

A major goal is to generate as many statistically independent samples as possible. Hence, cameras should be set far enough apart that the likelihood that they are sampling the same individuals is low. Because mammal species (and sexes) differ dramatically in the amount of space over which they move, obviously the distance between cameras in order to achieve independence of cameras will vary between species (and sexes). Except for the White-lipped Peccary and perhaps tapir, the species moving over the largest areas no doubt are the puma and jaguar, with more moderate movements and closer spacing no doubt being exhibited by the smaller cat species and most other medium-sized mammals. Hence, spacing between adjacent cameras should be chosen so as to minimize probability of sampling the same individual puma and jaguar, and this spacing should be adequate for most mammals.

Because home ranges of jaguars may be as much as 16 km across (and of unknown size in Petén), to be certain of adjacent camera sites being independent, cameras would have to be at least 16 km apart. This is obviously impractical, and would generate an absurdly small amount of data per effort expended. Moreover, it is not necessary that an "independent" sampling unit consist of a single camera station. Rather, several cameras could be put within a relatively compact area, with each such camera cluster comprising the basic sample unit (i.e., n = 1). In fact, this design has been widely used in carnivore sampling by the U.S. Fish and Wildlife Service, based on transects with several baited track-detection stations rather than cameras (Linhart and Knowlton 1975, Roughton and Sweeny 1982). Initially USFWS used transects of 50 stations at 0.3 mile intervals along them, run for 4 consecutive days. Because individual carnivores sometimes visited more than one station, and also visited stations on more than one night of a 4-night sample period, the entire transect of 50 stations and four nights of effort constituted one independent sample, i.e., n = 1. Because of the low efficiency of this format, the sampling design was later changed to 10 scent stations per transect, run for only one night, allowing the same worker to generate several times more independent data points per day of effort (Roughton and Sweeny 1982).

In an effort to strike a compromise, to achieve independent or nearly independent samples, and yet be able to fit several samples into a relatively small area, we propose the following:

1. Put cameras no closer than 2 km apart. (This could be raised to 3 km).

2. Set them across natural and lightly-used man-made trails, without bait.

3. Leave each camera out for a one-week period. The work schedule then would look like this; Monday through Friday of week one, a worker or team of two would put out X cameras per day (based on experimentation to see how many is practical--perhaps 5 to 7 on average). The following week, collect the cameras placed out on the corresponding day one week earlier; on these days, other sampling could also be carried out, or the same cameras could be placed elsewhere.

4. Assuming an average of at least 5 cameras are placed per day, this would allow 25 sites to be sampled every two weeks or every week, for 50 to 100 camera-weeks or 350 to 700 camera-nights sampled per month. This would require 25 cameras in operation, at $175 each, or $4,375 initial purchase cost, not including replacements for stolen or damaged cameras, or costs of batteries, film and development. Periodic replacement of cameras and automatic trigger equipment no doubt will be necessary, perhaps every two to three years.

5. We recommend that experimentation be conducted to see during what time of year returns are best. Unless this shows a decided advantage to some other time of year, we recommend that sampling be restricted to the dry season, i.e., 1 February or earlier to 1 June, a period of four months.

6. A 4-month sampling period thus would generate 200 to 400 camera-weeks of sampling, or 1400 to 2800 camera-nights.

7. Extrapolating from Kawanishi's (1995) 7 to 13.9 % success rate using this method at Tikal, we might expect from about 100 to 400 animal photos.

8. Based on Kawanishi's (1995) results, we might expect 100 photos to include 5-7 each of ocelot, margay and puma, and perhaps one jaguar or so. This might be regarded a phenomenal amount of effort for one jaguar detection, though this is in fact a substantial amount of information about the overall carnivore community.

9. If possible, double or triple this sampling effort per year by fielding more personnel equipped with more cameras, still working within the same February-May period.

10. Extending the sampling period into another season would not allow an extension of coverage to other areas unless it is demonstrated that detection rates do not change importantly between seasons.

11. An extended sampling season, however, could be used in order to conduct repeated sampling at the same sites sampled earlier. Though the first priority is to sample a large number of sites, there is also merit in acquiring a more thorough sampling of the large mammal community at a limited number of study areas (perhaps three); for such an effort, repeated sampling at the same or different sites within these study areas throughout much of the year could be desirable.

Other comments

Potentially, this method could be used to estimate density of target species, e.g., jaguar and puma, via capture/recapture estimation methods. However, this would rely on either (1) ability to recognize individuals in photos (potentially possible for spotted cats but unlikely for pumas or other species), or (2) capturing and marking animals. Capturing and marking jaguars, puma, or other large mammals is certainly beyond the scope of a mere monitoring program unless this is made a very high priority and very substantial funding and expertise devoted to it). In addition, this goal would require extensive sampling in the area(s) of interest, again requiring major funding and expertise, and would not yield information about multiple areas of the reserve without even greater devotion of resources. In short, it is quite unlikely that this is a reasonable goal unless it is deemed of the highest priority and unless large amounts of funding are available. An example of such an approach is given by Mace et al. (1994). Additional discussion of use of automatic cameras for monitoring mammals is presented in Wilson et al. (1996).

2. Trip-wire cameras

A less costly (in terms of camera purchase) method is use of cheap cameras with built-in flash unit, modified to be triggered by a trigger line attached to a bait. The advantage of this method is that initial cost of cameras ($20) is substantially less than that for Trail Timer cameras ($175). The chief disadvantage is that, since this approach uses bait, it is selective as to those species attracted to the bait, unlike the Trail Timer approach, which gives a less biassed sample of the mammal community. Another disadvantage is that cameras must be modified; this is not so onerous, however, as detailed methods are described by Jones and Raphael (1993) and Zielinski and Kucera (1995).

3. Track-stations with scent attractants

As mentioned above, the USFWS conducts an annual sampling of carnivore abundance, focused on coyotes (Linhart and Knowlton 1975). The same technique is routinely used to sample bobcat populations in some states (Diefenbach et al. 1994) and has been used on other carnivores elswhere (e.g., Conner et al. 1983, Travaini et al. 1996). The USFWS method uses lines of 50 (earlier) or 10 (now) scent stations at 0.3 mile intervals. At each station, a 1-m diameter circle is prepared as a surface on which to identify mammals that visited, by viewing their tracks. A great deal of experimentation has gone into choice of a standard scent to use as an attractant (Roughton and Sweeny 1982, Roughton 1982).

This method would probably work for sampling cat populations in the MBR, but has several disadvantages in comparison to the Trail Timer camera method. The main drawback is that this method relies on use of scent attractants; without them, the incidence of tracks would likely be too low to make this method effective. Use of scent attractants biasses results; while this method may be good for tracking carnivore populations, it would be less satisfactory with respect to other members of the mammal community. Another serious drawback is the high level of proficiency required in order to reliably indentify tracks of Petén's diverse mammal community. This problem is surmountable but would require diligent study, practice, and record-keeping; maintaining consistency over the years, through changes of personnel, would be far more problematic than with a camera-based method.

Methods

If this approach is selected, we recommend the following methods, drawing heavily on Roughton and Sweeny (1982) and Diefenbach et al. (1994), though Zielinski and Kucera (1995) should be studied before selecting methods.

1. Each track-detection station is a 1 m diameter circle where the earth is smoothed and a thin layer of dry, finely-powdered lime (commercially available slack lime) is sifted through a window screen to create a uniform surface for track deposition. Diefenbach et al. (1994) strongly warn against using any kind of sand as a tracking medium. If lime powder does not work well as a tracking medium, or if there is difficulty in identifying tracks by this method, we recommend switching to use of smoked

aluminum track plates as described by Barrett (1983) and Zielinski and Kucera (1995).

2. Stations should be established 500 m apart along lightly-used trails and logging roads.

3. A standardized number of stations should be established on each transect; we recommend five stations per transect; the first station should be 250 m from the entry point (in most cases the main road); hence the required transect length is 2.25 km.

4. Each sample unit should be of two transects, totalling 10 detection stations.

5. All stations within a sampling unit should be at least 500 m apart; i.e., transects within a sampling unit can be as close as 500 m side by side, or one can be a linear extension of another. This approach is valid because transects within a sampling unit are not considered replicates, and are summed to produce one data point.

6. Each station is operated for one night per sampling event.

7. A sample unit, i.e., a single data point, consists of the number of stations out of 10 total, at which the species in question was detected in one night of sampling, expressed as a percent of 10 stations; hence, this quantity can take the value of 0, 10, 20, etc. If any of the 10 stations are inoperable, the divisor of the fraction is adjusted accordingly.

8. A standardized attractant is used in the same way at all stations, within and between years. It is critical that the attractant not be changed between years, as this would remove all ability to detect changes in mammal populations between years. Moreover, the quality and hence attractiveness of the attractant must be rigidly standardized between stations and years, as well as the quantity and manner of presentation. See section below on choice and presentation of attractants.

9. Independent sampling units (i.e. clusters of two transects, totalling 10 stations) must be at least 3 km apart at their most proximal portions; where possible, 5 km or more between transects is desirable.

10. Experimentation must reveal how many sampling units can be established per field worker per day; we suspect that on average, five to seven sampling units or 50-70 stations per day can be established by one worker (Roughton and Sweeny 1982). If, as suggested by Roughton and Sweeny (1982), on subsequent days, the worker checks the previous day's stations and puts out five or more new lines, then by the end of the fifth day, he will have observed 20 or more sample units. We recommend that two workers work independently in a given area (assuming they can remain in radio contact, for safety reasons), between them observing 40 or more sample units, for one night each, per 5-day work week. Thus, during a four month dry season, a two-person team devoted to this method full-time could accumulate as many as n = 640 data points (each consisting of one 10-station track transect for one night.) It may be deemed more desirable for personnel to work in teams of two for the sake of safety, consistency of methods, and to prevent boredom.

11. Workers must undergo thorough training, practice, and testing for identification of tracks, as well as standardization of all aspects of methodology. Various reference sources for track identification should be collected beforehand, beginning with Murie (1975), Schaller and Crawshaw (1980), Tayor and Raphael (1988), and Zielinski and Kucera (1995). Experts should be consulted for advice on track identification, and a series of plaster casts, photos, and sketches of tracks of known identity should be compiled, making use of regional zoos and animal rescue facilities.

12. A data sheet should be use for recording results in the field, and this should provide for cases of limited confusion, e.g., "small cat", "jaguar or puma", unidentified, unidentified ungulate, peccary species, etc.

13. A permanent record of an example imprint from each track event recorded should be made by tracing the track outline with indelible marker (e.g., "Sharpie") on a transparent plastic or mylar sheet, with relevant data on date, locality and observer also on the same sheet. These should be filed along with the related field data sheets in ring binders. A library of known track outlines and a key to identification should be created, following the examples of Taylor and Raphael (1988) and Zielinski and Kucera (1995).

14. Once established, the same transects should be sampled at each resampling event (within and between years). In addition, the same stations should be used, though perhaps varying precise station locality by 20-30 m in order to minimizing learning and

habituation. In no case should repeated baiting be conducted at brief intervals at the same exact site, as this may produce habituation and decreased response by target species.

15. The number of transects to sample within a given area, and the number of times, if any, it is desirable to sample each transect per year, must be determined formally by a statistician, employing existing data and/or data from the first year of sampling.

Choice and presentation of attractants

The biggest choice to be made is in the identity of attractant to be used. We suggest that initial experimentation be conducted with various attractants, to see which is most effective. This experimentation must be done in a rigorous and statistically sound fashion, and the results analyzed formally via statistical tests; we recommend following the experimental design outlined precisely for such research by Roughton and Bowden (1979). Key considerations for choice of attractants are that an attractant should be: (1) chemically invariable from year to year, (2) readily obtainable, (3) affordable, and (4) consistently attractive to target species, especially the jaguar and puma.

We recommend that primary emphasis be given to testing the efficacy of Fatty Acid Scent (FAS; see formula below), which has been widely used as an attractant for canids and bobcats in the U.S., and found to be attractive to a variety of carnivora. This attractant should be invariant in characteristics over time, which is a critical consideration. Alternatively, a commercially available attractant (this or another) could be used, providing the chemical formula is fully known, so that it could be synthesized in the future if it becomes commercially unavailable. We also recommend experimentation with locally-available potential attractants, provided a high degree of consistency in the nature of these can be assured. In particular, we recommend experimentation with fresh blood (cattle or pig, not to be used interchangeably) from local slaughter houses; this would have to be kept at a constant degree of refrigeration and presumably for a limited amount of time, in order to retain consistent characteristics. The difficulty of refrigerating blood adequately for more than a week, especially when sampling in remote parts of the reserve such as Dos Lagunas and Rio Azul, probably argues against using blood or other perishable attractants and strongly underlines the desirability of using a synthesizable formula such as FAS.

The formula for FAS is given by Roughton (1982) as:

Percentage (by volume) of volatile fatty acids in fatty acid scent (FAS).

Acid[1]	Percent
Acetic	1.48
Propionic	4.42
Isobutyric	1.60
Butyric	26.70
Isovaleric (3-methyl-butanoic)	1.79
Valeric	8.14
Isocaproic (4-methyl-valeric)	2.12
Caproic (hexanoic)	30.27
Heptanoic	12.71
Caprylic (octanoic)	10.80

[1] Some chemical supply houses catalog by the alternative nomenclature given in parentheses.

Method of presentation of the selected attractant should be consistent. If FAS is used, we recommend using the method described by Roughton and Sweeny (1982). They recommend making plaster disks, 25 mm diameter by 5 mm in thickness. These are immersed for one hour in FAS. A disk is simply placed in the center of each track station. The shape of the disk and, especially, the mass of each disk, must be rigorously standardized, as a larger or smaller disk would absorb more or less FAS, affecting the duration and/or strength of its attractiveness accordingly; we suggest using a widely available item as a form for making the plaster disks, such as a plastic cap of some kind. Alternatively, a set volume of FAS may simply be deposited by syringe on the ground, or a log or dead limb at each tracking station. Alternative baits are discussed by Zielinski and Kucera

(1995). Desirable conditions and permissible shelf-life for storage of FAS and its component reagents should also be investigated.

Discussion

A spacing of 3 km between transects is not truly independent as far as puma and jaguar are concerned. However, since individuals often overlap in home range, there should potentially be a few to several individuals available for detection at any point in space, such that a detection in one portion of a home range does not preclude the possibility of a simultaneous detection elsewhere in the same home range. The probability of a given individual visiting more than one transect per night should be relatively low. The above considerations probably mean that one can obtain reasonably independent data on transects as close as 3 km apart. Where possible, transects should be 5 km or more apart, generating a greater degree of independence between transects.

Roughton and Sweeny (1982) caution that efficacy of this method may vary between sites and habitats. Hence, this approach is not highly appropriate for comparing sites; rather, it is more appropriate for detecting changes at a given site over time, which is our primary goal in monitoring. Roughton and Sweeny (1982) also make recommendations as to statistical tests optimal for analysis of resulting data; they suggest use of randomization tests where possible, and nonparametric tests where it is not possible.

Diefenbach et al. (1994) evaluated this method for bobcats, comparing results to known populations of bobcats reintroduced on an island. They concluded that single annual scent-station surveys had a poor ability to estimate populations. They recommended use of four replicate surveys per year; this degree of replication gave an 80 % probability of detecting only large changes (25 % or more) in population density. They offer many other recommendations germane to sampling carnivores in the MBR.

4. Track surveys

Another method that has been tested and successfully used for monitoring change in puma populations is that of searching dirt roads or sandy arroyos for tracks. Two studies (Van Dyke et al. 1986, Van Sickle and Lindzey 1992) compared frequency of tracks to known densities and movements of radio-collared cougars. They found that a reasonable amount of the variation in incidence of tracks crossing roads was attributable to the number of cougar home-ranges through which the roads crossed. However, variable and non-random sampling of cougar home-ranges by roads presented a problem; hence this method could not be used to compare cougar abundance between areas because roads probably sampled cougar populations differently in different areas. Nonetheless, where roads were adequately distributed with repect to cougar home ranges, this method could be useful, especially to detect reasonably large changes in cougar populations over time. Another study (Beier and Cunningham 1996) subjected data from track searches in dry arroyos (preferred cougar travel corridors), to computer simulations, in order to explore the power of this method to detect changes in cougar populations; this study also verified the practicality of this method.

Unfortunately, tracking conditions in the MBR probably are not appropriate for use of this method. During the dry season, this method could be used if dusty trails or little-used roads were abundant enough and had adequately dusty surfaces; however, we strongly doubt that this is the case. During the wet season, this method could be used along muddy roads and trails, but there are several drawbacks to the method. First, appropriately muddy conditions are patchy and highly variable from one trail or road to another; this limits one's ability to use this method in a standardized fashion. Second, rains occur frequently and at sporadic intervals; this both shortens the window of time being sampled with each search, and makes for variable (and unknown) time windows being sampled, which introduces a large and unknown amount of error into the method. Finally, this method requires substantial training and experience in track identification.

We suggest that this method be used by resource guards on patrol, who should watch for tracks and record them. We do not suggest it be used as a replacement for automatic camera or scent/track stations, except possibly as suggested below.

5. **Possible importance of monitoring large cats near bodies of water**

Jaguars have often been described as being closely associated with bodies of water, and this was verified in Brazil by Crawshaw and Quigley (1991). Many portions of the MBR are poorly endowed with water bodies compared to the two Brazilian and the Belizian site where jaguar densities have been formally studied. Whether this scarcity of water affects jaguar densities in the MBR is unkown, but this observation suggest two things. First, the most important areas for jaguar conservation may prove to be the vicinities of water bodies (including small aguadas), and second, an effective means of monitoring these cats may be to sample in the vicinity of water bodies (H. Quigley, pers. commun.). If such a monitoring strategy is employed, it may be possible to rely solely on natural tracking substrate (mud), and to avoid the more complicated and costly methods described above.

6. Other methods

1. Diurnal and nocturnal visual census along transects

Kawanishi (1995) presented preliminary data of H. Quigly and M. Gonzalez resulting from diurnal transect censuses of mammals at Tikal. Based on those results, it appears that this method was effective for counting howler and spider monkeys, but relatively ineffective for most other medium-to-large mammals. Based on experience, we doubt also whether nocturnal visual transects would even remotely approach the efficacy of the automatic camera method, or of scent-baited track stations as described above; hence we also reject nocturnal transects as a general method. Conceivably, however, diurnal or nocturnal transects could be useful for special cases.

2. Search with dogs

If a fairly refined estimate of population density is desired, it will be necessary to focus, probably on a single species. In this case, methods would be adapted for this species, and might be quite specialized. For example, if good estimates of density of tepezcuintle or armadillo are desired, then one might use a dog in order to sniff out occupied burrows over a unit area of habitat; this is probably the best way, short of intensive radio-telemetry studies, to estimate density of these species. Use of dogs for non-burrow-dwelling species would be less practical.

APPENDIX 7. EXAMPLE DATA SHEET FOR RECORDING OBSERVATIONS MADE DURING RESOURCE GUARD PATROLS

The following two pages constitute this appendix.

Formulario de reporte de observaciones de patrullaje

Reporte diario para ___________ ___________ _____ ______Completado por___________________________
(día) (mes) (fecha) (año) (nombre)

Personas participando en actividades reportadas aquí____

Actividad durante la cual observaciones/entrevistas fueron hechos:______________________________________

____

Sitios/ruta de patrullaje/observación: desde ____

hasta ____________________________________, vía (ruta)____

____

Salió __________________________de __________ Llegó a_________________________a las______________
(punto de partido) (hora) (destinación) (hora)

Modo de viaje ________________________ # de personas viajando_________; # observando________________

Condiciones de observación: ruido hecho por el grupo ____________________________

condiciones para huellas________________indicar lodo o polvo? ______________ Tiempo: lloviendo? ________
(bueno/malo)
mojado? ____________ asoleado? _____________ nuboso? ____________ viento? _____________.

OBSERVACIONES

Especie Número de individuos u observaciones de seña; tipos de seña observada; localidades

jaguar____

leon____

tigrillo____

jaguarundi____

gato de monte____

perico ligero____

danto____

venado____

cabro____

tepescuintle____

cereque____

armadillo____

oso hormiguero____

pisote____

jabali____

coche de monte____

faisan____

cojolita____

pavo petenero____

jabiru____

guacamaya____

cocodrilo____

otras especies de interés:____

Tumba de bosque primario____

Tumba de guamil____

Construcción o mejoramiento de caminos____

Quemas agrícolas____

Fuego escapado____

Incendios forestales____

Cambios de presencia/población/actividad
humana____

Otras notas:

Personas entrevistadas (nombres, localidades, tópicos platicados):

APPENDIX 8 - INFORMATION SOURCES FOR BUTTERFLY MONITORING METHODS

The chief source for indicators and sampling methods for butterfly monitoring in the MBR should be Méndez (1997), along with consultation with Claudio Méndez, Nicholas Haddad, and colleagues. In addition, the following literature may be helpful.

Austin, G. T., N. M. Haddad, C. Méndez, T. D. Sisk, D. D. Murphy, A. E. Launer, and P. R. Ehrlich. 1996. Annotated checklist of the butterflies of the Tikal National Park area of Guatemala. Tropical Lepidoptera 7:21-37.

Brown, K. S. 1991. conservation of neotropical environments: insects as indicators. In: N. M. Collins and J. A. Thomas (eds), The conservation of insects and their habitats. 350-404. Academic Press, London.

Daily, G. C., and P. R. Ehrlich. 1995. Preservation of biodiversity in small rainforest patches: rapid evaluations using butterfly trapping. Biodiversity and Conservation 4:35-55.

DeVries, P. J. 1987. The butterflies of Costa Rica and their natural history. Princeton University Press.

Gadagkar, R., K. Chandrashekara, and P. Nair. 1990. Insect species diversity in the tropics: sampling methods and a case study. J. Bombay Nat. Hist. Society 87:337-353. ((used a variety of cheap sampling methods))

Gaston, k. J. and B. H. McArdle. 1993. All else is not equal: temporal population variability and insect conservation. In: Gaston, K. J., t. R. New, and M. J. Samways (eds), Perspectives on insect conservation. Intercept, Andover, U.K.

Hill, J. K., K. C. Hamer, L. A. Lace, and W. M. T. Banham. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. J. Applied Ecology 32:754-760.

Méndez, C. A. 1997. Licensiatura thesis, Universidad de San Carlos de Guatemala.

Méndez, C. A., T. D. Sisk, and N. M. Haddad. 1995. Beyond birds: multitaxonomic monitoring programs provide a broad measure of tropical biodiversity. pp. 451-456 *in* J. A. Bisonette and P. R. Krausman, eds. Integrating people and wildlife for a sustainable future. The Wildlife Society, Bethesda, MD.

Natuhara, Y., C. Imai, M. Ishii, Y. Sakuratani, and S. Tanaka. 1996. Reliability of transect-count method for monitoring butterfly communities 1. Repeated counts in an urban park. Jpn. J. Environ. Zool. 8:13-22.

Pollard, E. 1977. A method for assessing changes in abundance of butterflies. Biological Conservation 12:115-131.

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Pollard, E. and T. J. Yates. 1993. Monitoring butterflies for ecology and conservation. Chapman and Hall, London.

Sparrow, H., T. Sisk, P. Ehrlich, and D. Murphy. 1994. Techniques and guidelines for monitoring Neotropical butterflies. Conservation Biology 8:800-9.

Spellerberg, I. F. 1991. Monitoring ecological change. Cambridge Univ. Press, Cambridge.

Stork, N. E. 1994. Inventories of biodiversity: more than a question of numbers. pp. 81-100 in P. L. Forey, C. J. Humphries, and R. I. Vane-Wright (eds), Systematic and conservation evaluation. The Systematics Association Special Volume No. 50. Oxford Science Publications.

Stork, N. E. 1995. Measuring and inventorying arthropod diversity in temperate and tropical forests. In: T. Boyle (ed), Measuring and monitoring biodiversity in tropical and temperate forests. CIFOR, Bogor, Indonesia.

Williams, K. S. 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. Restoration Ecology 1:107-116.

APPENDIX 9. SAMPLING METHODS FOR AMPHIBIANS

Before final selection of amphibian sampling methods, further consultation with amphibian specialists, and possibly experimentation with various field methods, should be conducted. Potential methods are discussed in Heyer et al. (1994) and Pearman et al. (1995). Here we have considered the merits of 10 sampling methods described in chapter 6 of Heyer et al. (1994), and a few additional methods described in chapter 7 of the same publication. Of these methods, we suggest that systematic, periodic counts of adult anurans (frogs and toads) at breeding ponds, is the most useful method for monitoring in the MBR. Other potentially useful methods include visual encounter surveys, quadrat or transect sampling, sampling with artificial pools, and point or transect counts via acoustic recognition. However, we feel that these other methods have serious drawbacks for use in the MBR. Visual encounter surveys rely heavily on the ability of the investigator to sight cryptic amphibians (in large part tree frogs) among the dense and complex vegetation; hence this method seems inordinately vulnerable to inter-observer biasses. Quadrat sampling of leaf-litter is expected to involve a large amount of effort for the amount of data collected; also, a substantial portion of the amphibian fauna of the MBR is made up of tree frogs which are not expected to be well-sampled by such a method. Transect methods are expected to suffer the same problems as the two methods just discussed. Artificial breeding pools may very well attract many frogs and toads in Petén's dry forests, but involve the additional expense of purchasing receptacles, the difficulty of digging holes in the often shallow soil in order to make these pools flush with the ground surface, and related disadvantages; in short, we do not see a compelling advantage of that method over that of sampling breeding sites that already exist on the landscape, be they naturally-occurring or anthropogenic in origin. With adequate resources for, and experience with recognition of frog and toad vocalizations, point or transect counts that rely on acoustical detection and recognition could be worthwhile, as a supplement to, or in place of counts at breeding sites. Other methods discussed in Heyer et al. (1994) have even more compelling disadvantages, we feel, relative to censusing breeding pools. Hence the remainder of our comments here will center on census of existing breeding sites.

Scott and Woodward (1994) give a thorough discussion of methods for, and complications of, counting amphibians at breeding sites. Probably the greatest complication of this method is the fact that breeding activity (and presence of adults) at given breeding sites is notoriously variable from year to year in many amphibian populations, and a given pond often is not used every year by a given species. Apparently such high variability is common even in healthy amphibian populations, and may make it difficult to detect changes in amphibian populations over time amid the large amount of natural background "noise" in the data. Despite this drawback, we feel that this method is useful for pond-breeding species.

Based partly on Scott and Woodward (1994), we recommend the following:

1. Select three to five study areas within the MBR; these need to be areas accessible during the rainy season.

2. Selection of ponds to sample:

a. At each study area, based on visits during the rainy season, select 5-10 ponds where frog breeding activity is observed. Ideally, these would be selected such that at least 3-5 ponds are comparable in terms not only of the conditions presented by the pond itself, but in terms of the surrounding habitat, i.e., the habitat from which the pond attracts anurans. Hence, these 3-5 ponds would be considered spatial replicates within that study area, for that habitat type.

b. Within each study area, two approaches to pond selection are possible. First, an effort could be made to select ponds sampling surrounding habitat ranging from pristine to altered (e.g., primary forest to slash-and-burn mosaic); this would demand the sampling of more ponds, as a bare minimum of 3-5 ponds should probably be sampled within each "habitat type" (and quite possibly 10-20 per habitat type would need to be sampled in order to generate high statistical power). However, the principal goal of amphibian sampling, as conceived here, is not to document changes of the amphibian community in response to local, physical alteration of the plant community or other habitat features. Rather, amphibians are proposed here as monitoring targets principally because of their presumed sensitivity to global/atmospheric factors. To be useful in this regard, we should sample amphibians in areas that remain nominally unaffected by local factors. Hence, replicate ponds should be sought in the most pristine areas available, e.g., within core areas or other sites with no or minimal habitat alteration or other local stressors.

3. Devise a standardized data sheet and protocol for censusing ponds. The general protocol may need to be adapted to each

pond. Small ponds should be searched entirely, whereas ponds too large for this should have the same subsample censused each time; in this case, it is essential that the same segment be unequivocably recognized and delimited during all censuses, including in subsequent years--for this, a polaroid photograph may be helpful, and a detailed written description of the portion censused is essential.

4. To facilitate search for breeding adults, the pond surface, shore, and back-shore segments should be divided into quadrants for search, using flagging and perhaps hip-chain string to mark quadrant boundaries. Quadrants should be small enough to facilitate complete search of each.

5. Sample censuses should be conducted at different times of day and night, in order to determine diel patterns of presence of various species. If possible, select a single period, probably at night, that is adequate for sampling all species.

6. Each site will need to be censused at least three times during the breeding season. Trial sampling should be conducted in order to determine the duration of the breeding season, the variability of dates of breeding activity from year to year, degree of association of breeding activity with onset of rainy season and with subsequent patterns of rain and water levels, and to ascertain how many times and at what time of the season it is necessary to census each pond in order to adequately characterize the pond's use by anurans in a given year.

Complicating factors

The greatest drawback of counting anurans at breeding sites is that counts of adults present at one or more dates do not necessarily reveal the number of individuals using the site. Because adults no doubt come to, remain at, and leave the pond at unknown rates, the total number of adults using the pond will remain unknown unless efforts are made to ascertain this number, for example, through mark and recapture methods. Hence, unless the peak number of frogs present at a point in time is correlated with the total number of frogs using the pond during the season, simple totals of frogs counted during one or more visits may be unrelated to the number of frogs using the site during the season. Because of these complications, we recommend thorough consultation with amphibian specialists prior to selecting one or more methods for monitoring amphibians; it may prove important to conduct mark-and-recapture population estimates, or at least estimates of rates of turnover of individuals present at the breeding sites from day to day. Or it may be that censuses of breeding sites should be abandoned in favor of some other method(s), possibly nocturnal transect searches through the forest (Pearman et al. 1995).

APPENDIX 10. OTHER SUGGESTED MONITORING DATA BASES TO MAINTAIN

1. Photo stations

One possible way to document changes of various sorts (habitat, farming practices, erosion, human dwellings), is to take photographs repeatedly over time at the same site. This has been used, for example, to document vegetation change in the arid northamerican southwest. The advisability of this approach should be evaluated. Certainly, IDAEH should consider such an approach to monitoring tourism impacts on archeological structures.

2. Forest fire frequency

Frequency of forest fires may be a desirable indicator to measure. Frequency of forest fires is no doubt a function of several factors including (1) frequency of escape of anthropogenic fire, (2) dryness of weather, (3) degree of forest thinning by logging and fuelwood cutting, (4) frequency of blow-downs, and perhaps other factors. The potential importance of this assessment endpoint is demonstrated by the observations of Uhl and Buschbacher (1985). These authors found that selectively logged forests in Amazonia were more susceptible to wildfire than were intact stands. Moreover, they attribute a catastrophic fire in Bornean rain forest to a drought in combination with prior logging. They state that "the potential for wildfires to cause wide-scale destruction of lowland evergreen rain forests is still only dimly recognized, but recent events are sounding an alert." Dr. Uhl continues to pursue this research theme in Amazonia (M. Schulze, pers. comm.), where he suspects that selective logging sets the stage for catastrophic fire in the residual forest stands. In the dry forests and drought-prone climate of northern Petén, any factor that leads to increased drying of the forest (e.g., selective logging, forest fragmentation) may set the stage for fire at least as much as it does in Amazonia.

A data base should be maintained on the frequency of forest fires by size and reserve unit. The underlying assessment endpoint would be susceptibility to fire, while the indicator measured could be frequency of fires above a certain size (say 10 or 100 ha) per year per management unit of the reserve. Data on fires should be collected routinely by resource guards on patrol, and entered into the fire data base after each patrol.

3. Frequency of insect irruptions

Susceptibility to various stressors has been proposed as a useful measure for characterizing ecosystem condition (Rapport 1989). One potential such measure is susceptibility to pest outbreaks, as measured by their frequency of occurence. Though tropical forests are often characterized as climatically and biologically stable, in reality they often are subject to substantial variability in climate and weather and they are also subject to irruptions, such as those of various defoliating insects. Recent evidence of such susceptibility comes from the MBR itself. In 1995, two noteworthy insect irruptions occurred throughout Tikal National Park, and at least one of them extended over large areas of the MBR. The large larvae (known locally as "gallina ciega") of a scarabeid beetle, apparently *Enema endemion* (Enio Cano, pers. commun.), appeared in huge numbers at the onset of the rainy season. They consumed essentially all the leaflitter over large areas of the forest floor, and their burrowing activities brought tons of soil to the surface. Though gallina ciega are observed in all or most years, the numbers observed in 1995, and the magnitude of accompanying excavation and leaf litter consumption, were without parallel in the memory of most Peteneros we questioned. At the same time, one or more unknown defoliating insects, probably a lepidopteran, almost completely defoliated the population of *Pouteria reticulata*, "Zapotillo hoja-fina" in Tikal National Park. This is one of the most abundant trees in this portion of the MBR, and hence its defoliation temporarily altered the subcanopy light regime of the forest to a degree. Other tree species also suffered noticeable but lesser defoliation.

We suspect that the *Enema* irruption was causally related to several months of relative drought (Whitacre, in prep.); in some other cases, insect irruptions have been related to weather events, including drought. Insect irruptions may occur partly in response to lowered resistance of their food plants. Drought is only one of several factors that can lead to such lowered resistance. We propose that collecting data on insect irruptions may be a useful way to track changes in the ecology of forests of the MBR. A separate data base on noteworthy populations of insects and other organisms should be maintained. Even casual, anecdotal information should be reported, but should be followed up where possible by more thorough documentation. It is very important that several specimens of the insects involved be preserved in alcohol for identification. These should be deposited with the chief of the monitoring program, who should arrange for identification and placement of voucher specimens in one or more research museums.

4) Data bases on sightings and other evidence of cats (jaguar, puma, ocelot, margay, and jaguarundi)

Our focus here is especially on the jaguar and puma, for reasons given earlier. In addition to formal sampling methods described earlier, it should be possible to collect data on occurrence of theses species using a variety of less demanding methods. We recommend the following data collection efforts, with a data base maintained for each method:

a.) Reports of all lion and jaguar sightings that it is possible to collect. All government and NGO personnel working in the MBR should be encouraged to report all sightings they personally make, and all sightings by others, for which they can gather minimal particulars. Such reports should contain: 1) name of person making sighting, 2) person's place of dwelling, 3) date of sighting, 4) time of day of sighting, and 5) gross locality of sighting (e.g., along road between Cruce a Dos Aguadas and San Miguel) and, where possible, 6) more detailed locality of sighting (e.g., 7 km N. of Cruce a Dos Aguadas). Though such data will only reveal that these species occur in certain areas (as opposed to conveying information about their abundance), this information in itself is useful.

b.) Reports on sightings are much more valuable if they are accompanied by a measure of sampling effort. For example, the fact that a jaguar was seen has much greater meaning if we know that it was the only jaguar seen during 20 days of dawn-to-dusk hiking through trails within a remote area of the reserve, or that it was seen during a single drive into Tikal National Park and back out. However, it is not practical for everyone working in the reserve to keep track of all their movements which may be regarded as "sampling effort". It is, however, practical to require this of CONAP resource guards and perhaps certain other personnel working in the reserve. The patrol and vigilance activities of CONAP resource guards should be regarded largely as monitoring efforts, and data on sampling effort and observations of certain items of importance should be faithfully recorded by all resource guards. To achieve this, resource guards must record not only sightings but also "sampling effort" very carefully, using standard report formats. An example data sheet for use during resource guard patrolling is shown in Appendix 7.

5) Data bases for other species and phenomena

Data bases should be maintained, in order to record opportunistic sightings or evidence of the following species and phenomena:

a. suspected sightings of Harpy Eagles - The harpy eagle is apparently very rare in the reserve. The point counts described earlier will only partly meet the needs of monitoring this species. In addition, any suspected sightings should be investigated by experienced personnel, and physical evidence (both current and historical) collected when available; this should be done throughout the reserve.

b. sightings and nesting of Scarlet Macaws - Population tendencies of the scarlet macaw can be monitored partly through the point counts mentioned earlier, but additional efforts will be needed. Probably the most important single effort will be to continue the monitoring efforts underway at El Peru; it is important to monitor the number of birds in the area, the number and success rate of nesting attempts, and causes of nest failure. Any other known areas of concentrated nesting should be likewise monitored. In addition, it would be worthwhile to continue to search for additional areas of macaw nesting and other usage; such search can be concentrated in the western half of the reserve, as there does not appear to be a macaw population in the reserve's eastern half.

c. sightings/evidence of white-lipped peccaries - White-lipped peccaries, due to their far-flung wandering in large herds, will be virtually impossible to sample by any routine sampling method. We recommend gathering information about this species by recording the observations of guardarecursos during patrol and other activities; this should be done throughout the reserve.

d. sightings and nesting of Jabiru storks

e. sightings, nest site occupancy, and nesting of Orange-breasted Falcon

f. other notable events or observations of biological importance

g. data base listing exotic species known or believed to be in or near the MBR

APPENDIX 11. OTHER TAXA FOR POTENTIAL USE AS INDICATORS OF WITHIN-HABITAT BIOTIC INTEGRITY OF THE MBR

A. Taxonomic groups:

Bats - Bats are diverse ecologically and in number of species, and have been successfully used as indicators of forest alteration (Fenton et al. 1992). They would be most practical for use if it is possible to sample them via existing "bat detector" instruments that allow identification of free-flying bats at least to the generic level, through their ultrasonic vocalizations. However, adequate species resolution of Petén's diverse bat fauna via this method seems unlikely. The other alternative is use of mist nets, which implies more complications (rabies precautions).

Rodents - Rodents have been used as ecological indicators in the MBR (Roling 1992). Rodents are practical in that they may be sampled via live-trapping. One limitation, however, is that species richness in the MBR is limited; for this reason, we feel they are not a high priority group for such usage.

Forest-floor reptiles - These could be sampled by searching through leaf litter on a few meters square plot of florest floor. However, because of expected low encounter rates, we feel this would yield little information per unit effort in comparison with the monitoring targets we have specified.

Crickets, katydids - This diverse group would be especially practical for monitoring if it is possible to use their vocalizations as a census tool. To evaluate this possibility, it is necessary to see whether there is adequate existing knowledge and recordings of species vocalizations. A potential problem is that some of these high-pitched calls may not be equally audible to different people, as ability to hear them may decrease with age. May also be sampled by black light.

Sphingid moths - Possibly migrate between different areas on a local/regional scale; research is needed to investigate this. Respond to black light.

Dung/carrion beetles - Have been shown to be sensitive to deforestation and size of forest fragments. Can be sampled via pitfall traps baited with feces or decomposing meat. Already being studied in the MBR (CCB/CECON 1996).

Wood-boring beetles - Perhaps not good for our monitoring purposes; may be buffered against environmental change by living within wood mass. May respond very slowly to change, e.g., may thrive for a time with death of trees.

Carabid beetles - Well known to be sensitive to habitat alteration and fragmentation in the north-temperate zone where they have been more studied. Many neotropical species are arboreal; what would be best sampling method?

Cerambycid beetles- Cerambycids are boldly patterned and colored, and should be easily sorted to species with minimal training; if they are diverse enough in the Petén's forests, they may be useful as an indicator group.

Passalid beetles - This group has proven useful as biogeographic indicators and as indicators of forest type in Guatemala (J. Schuster, pers. commun.).

Euglossine bees - Area-sensitive; important pollinators; can be censused visually or via trapping, using esters such as *cineole, methyl salicylate, skatole*, etc. as attractants.

other bees?

ants - Diverse; important determinants of invertebrate community attributes. Practical sampling methods exist, such as pitfall traps, collection and sifting of leaflitter and use of Burlese funnel.

Chrysomelid beetles - Diverse leaf-eaters; distinctive in form and color pattern, with morpho-species often readily distinguishable.

Leaf-hoppers/plant-hoppers (Homoptera) - Diverse plant suckers; many species are distinctive in appearance; morphospecies distinguishable to a point. These could be collected by beating and sweeping foliage, and by use of yellow pan traps (J. Schuster, pers. comm.) or Malaise traps.

Moths - Diverse but many may be difficult to identify. Can be sampled by black light.

Roaches - High biomass in leaf-litter; how diverse? Best collecting method probably collecting leaflitter and subjecting it to Burlese funnel or other separation methods such as sifting.

B. Groups defined by sampling methods:

leaf-litter arthropods - (insects, spiders, mites, pseudoscorpions, etc.); known to be sensitive to differences in humidity, hence should respond to canopy opening, etc. Sampling methods are pit-fall traps or gathering of leaflitter and sifting, or drying in Burlese funnel.

Species attracted to black light - Various insect groups respond, e.g. moths, katydids.

Insects attracted to flowering plants - One or more species of flowers could be systematically censused visually or via trapping, in order to document the insects attracted to it.

Species taken in window-pane traps - (A trap with vertical window pane fixed above liquid preservative; flying insects collide with glass and fall in preservative.) Collects flying insects in general, especially large ones. Yellow traps attract some Homoptera and parasitic Hymenoptera; however, the latter would be difficult to use, as sorting to morphospecies by non-specialists would be difficult.

Species taken in Malaise trap - A tentlike trap with a passive collecting device in one end; catches any flying insect. J. Schuster verifies that small, easily moved Malaise traps exist, at a cost of about $25 US.

Species taken by sweeping vegetation with net, or "beating" vegetation and drop-cloth - Collects insects on vegetation, especially small ones, and those that are not agile or alert.

Canopy fogging using fast-acting insecticide, tree sealed off in plastic tube; drop-cloth on forest floor - To attempt a "total" inventory of insects of the MBR, this would be a method of choice; would require sampling many trees of different species.

Insects attracted to existing light - A minimal monitoring program could conduct systematic census and collection of insects at existing light sources in areas with few artificial light sources amidst intact habitat; for example, the mercury vapor light above the french restaurant in Tikal National Park.

APPENDIX 12. OTHER POSSIBLE MONITORING TOPICS

1. Compliance monitoring

One distinct category of monitoring is that which is directed toward ensuring compliance with regulations governing activities such as commercial logging. This may be termed "compliance monitoring", and we do not address it here, except to state that we believe CONAP should establish regulations describing monitoring procedures to be conducted before, during, and after logging, in order to ensure and document compliance with applicable regulations. Detailed recommendations regarding this were provided by Whitacre (1993) in a report to CONAP.

2. Monitoring connectedness with other reserves and habitat areas

Though the MBR is very large, it is nonetheless important, for long-term conservation success at the regional and global scale, that the reserve maintain connectedness with other remaining habitat areas. Hence, it would be wise if the vegetation cover change analyses recommended herein could also direct attention to changes in connectedness between the MBR and nearby reserves and habitat areas, perhaps on a less-frequent basis than cover change analysis, and perhaps in a less formal manner.

3. Monitoring of ecosystem processes (biogeochemical and energy fluxes)

By "ecosystem processes", we mean interactions between biotic and abiotic elements, such as the capture and flow of the sun's energy, and the fluxes and cycling of nutrients and atmospheric gases. A recent paper examines this theme with respect to tropical forests (Silver et al. 1996). It would certainly be worth facilitating research on biogeochemical processes by collaborating scientists. We would not, however, rank this as an essential part of the monitoring program, relative to more locally pressing issues. We assume there is sufficient redundancy and resiliency in the biota with regard to energy capture and the capture, retention and transfer of nutrients, so that we are not headed for an imminent breakdown in basic ecosystem processes in the planet's tropical forests. This could prove false, however, if nitrogen-fixing bacteria and algae, nitrifying or denitrifying bacteria, microrhizae, or other key functional groups proved extremely vulnerable to insults such as global warming, increase in greenhouse gases, ozone thinning, or acid rain. We recommend that scientists advising CONAP and USAID remain alert to developments in this field, in the event they warrant reevaluation of the position recommended herein.

4. Monitoring of air and water quality

We do not currently recommend that ground water supplies or air and water pollution be monitored as part of the MBR monitoring program. Monitoring of water quality would certainly be worthwhile, but this is primarily a human health issue and not the obligation of those charged with management of the MBR. We strongly encourage that some agency concerned principally with human health (CONAMA?) initiate a program to monitor quality of municipal water sources and major lakes in and near the MBR.

Especially important is to increase the intensity of monitoring of Lago Petén Itzá. This lake is becoming increasingly polluted by raw sewage which stems in part from the burgeoning tourist industry. Chemical water quality of the lake is monitored by CONAMA Region VIII (SEGEPLAN 1996), though with what frequency we do not know. CONAMA should be encouraged to expand water analyses to include the microbiological parameters that they measure in drinking water sources (SEGEPLAN 1996), and to conduct such analyses at least annually if they do not already. Sampling should be designed so as to provide a thorough picture of "baseline" conditions existing throughout the lake, and to track changes in these over time. CONAP should acquire these data from CONAMA annually in order to form part of the annual monitoring report.

5. Monitor CONAP's presence and effectiveness.

It is worthwhile to monitor the effectivenes of CONAP itself. To do this, one could enter into the GIS all patrol routes taken, by date, and include all infrastructure (gates etc) that are actually manned. This would aid in periodically evaluating the adequacy of patrol, vigilance, and monitoring activities.

6. Monitoring ecological effects of tourism

In the core monitoring program proposed here, we have not suggested any efforts specifically to monitor the ecological effects of tourism. Indeed, the various monitoring components recommended could be planned so as to investigate tourism impacts. However, a design appropriate for examining tourism impacts would probably not be optimal for investigating other issues that we feel are of greater importance. It seems likely that the effects of tourism on the biota and ecological processes of the MBR, with few exceptions, are local in nature. For example, the heavily-travelled blacktop road that bisects the southern half of Tikal National Park very likely affects the movement, mortality patterns, and perhaps even the population density of some animal species in the vicinity. It is easy to imagine that this may be especially true for certain shy large mammals, such as jaguars and pumas. However, even if this is the case, it seems to us a low priority for monitoring. Tourism does have impacts on the arqueological structures themselves, as well as on park trails and other features. We feel that monitoring these impacts at arqueological sites is the responsibility of IDAEH.

At least one case of major environmental impacts of tourism does exist, however--that of pollution of Lake Petén Itzá. As indicated under point 4 above, it is important to increase efforts to monitor water quality in this lake.

APPENDIX 13. INVENTORY AND RESEARCH NEEDS

We do not feel it appropriate for us to attempt to state what topics of biological research merit support within the overall efforts to manage and protect the MBR. The potential field of biological research is infinitely broad, and it is extremely difficult to predict what kinds of research will make future contributions to conservation. For this reason, we recommend a policy of broad tolerance and encouragement of diverse avenues of biological research in the MBR. Nonetheless, it is possible to highlight a few topical areas in which research is especially important as an adjunct to conservation, management, and monitoring. No priority is implied by the order of the following list.

Biotic inventory.- Biotic inventory is a basic step which greatly facilitates development and improvement of reserve management and monitoring. Inventory provides the basic knowledge of what biota is present in a given area; such knowledge for the MBR is very incomplete. We recommend that biotic inventory of additional, unstudied portions of the reserve, and of taxonomic groups not yet addressed, be regarded as a high priority for reserve management. We do not believe that any single taxonomic group is of highest priority for inventory efforts; information on any taxonomic group adds to our knowledge of the biota of the reserve. It is highly practical to take advantage of the taxonomic interests of particular investigators and organizations currently active within the reserve or other prospective participants. We suggest that CONAP actively solicit such inventory efforts. Of special interest are the wetland ecosystems of the western portion of the reserve, as these have received very little attention from biologists.

Rapid ecological assessment.-- Related to the need for biotic inventory, it may be worth considering organizing a "rapid ecological assessment" team to briefly sample at many sites throughout the reserve where few biological data have been gathered. It would be highly effective to incorporate, at a minimum, expertise in birds, trees, butterflies and/or some other insect group, and possibly expertise with bats, herptiles, and some other floral group, perhaps orchids.

Confirming indicator functions of target groups.--One need is to confirm the supposed "indicator" value of those species groups or other parameters targeted for monitoring. We must verify the habitat affinities of such species if this has not been done, and test hypotheses concerning response to fragmentation, logging, and other habitat alterations.

Develop one of more Indices of Biotic Integrity for the MBR.--We must develop explicit means of using information derived from sampling of indicator suites in order to assay change and evaluate the biotic integrity of sites monitored and inventoried. A beginning toward an Index of Biotic Integrity based on birds was made by Whitacre (1997), but much additional developmental effort must be made.

Increasing sustainability of land uses.--Even more important is the need to find ways to increase the sustainability of prevalent land uses, and to make them more compatible with conservation goals. This is nowhere more critical than with slash-and-burn farming. A further research need is to identify the resiliency of game species to hunting and define acceptable hunting seasons and intensities.

Population viability analysis for vulnerable species.--We feel it would be valuable to solicit population viability analyses for the Jaguar, White-lipped Peccary, Scarlet Macaw, and perhaps other species that are rare in the reserve.

Scarlet Macaw status.--Another pressing research need is to study in detail the population size, trend, usage areas, and movements of the Scarlet Macaw in the MBR. If we do not soon conduct such detailed study, to determine what factors are causing population declines, and ways to intervene, we are liable to witness the extirpation of this northernmost remaining population within the next 10 to 20 years. What is needed is a well-funded, detailed study, probably using satellite radio telemetry.

Efficacy of conservation efforts.--Another useful task would be to study the efficacy of conservation and development efforts. For example, one could address the question--how effective is promotion of frijol abono as a means of slowing deforestation? This could be done by comparing rates of deforestation in areas where frijol abono has been promoted, with areas where it has not. Using satellite imagery and GIS, one could relate the amount of frijol abono use and associated promotion efforts, to subsequent land-use patterns. Another desirable effort, also approachable through GIS and remote sensing, would be to define areas and routes where creation of corridors to connect remaining forest fragments in the buffer zone could be most effective.

Intra-tropical migrant species.--It would be highly valuable to determine whether there are bird or insect species in the MBR that make local or regional migrations. It is likely that Scarlet Macaws and perhaps other frugivores do this, but no details are known. Also worth investigating would be Sphingid moths; in Costa Rica, some Sphingids are believed to make annual migrations of scores of km between areas with different rainfall patterns (Janzen 1987). It is possible that such a pattern occurs also in Petén, with moths moving to the wetter areas of southern Petén or Alta Verapaz during the dry season, and back to the drier northern Petén during the rainy season; it is unknown whether this occurs. If this is the case, then deforestation in southern Petén or Alta Verapaz could affect moth populations (and the plants they pollinate) within the MBR, even while the latter retains its forest cover.

Impacts of caoba and cedro logging.--The most significant alteration to the otherwise nearly pristine MBR has been the removal of most large caobas (*Swietenia macrophylla*), and to a lesser extent, Cedros (*Cedrela odorata*) during decades of selective logging. It would be worthwhile to conduct research aimed at detecting if and how this has altered the ecology of the MBR. Erwin (1982) estimates that, on average, each neotropical tree species has about 160 insect species associated specifically with it. Even if Erwin's estimate is drastically off target, it is likely that at least a few insect species are uniquely dependent on Caoba and Cedro. It would be worthwhile to encourage research to determine whether this is so, and whether the drastic reduction of large individuals of these trees has had an impact on the populations of these insects, and perhaps secondarily, on other insects or plants which may interact with these hypothetical specialist insects.

Documenting the total insect fauna of the MBR.--A highly ambitious but extremely worthwhile goal would be to make collections documenting the "total" list of insect species within the reserve. This would best be accomplished through canopy-fogging with a fast-acting, biodegradable insecticide (e.g., a pyrethrin), enclosing the target tree in a plastic tube, and collecting the insects knocked down on a drop-cloth over the forest floor (Erwin 1988). We suggest that CONAP and AID solicit the research community to undertake such an effort. We propose such an effort not because management of the MBR requires it, but rather, because of the important role played by the MBR in global conservation efforts. Due to its large size, the MBR is destined to be among the most effective conservation sites in the northern neotropics; hence, it would be good to know how many, and which, species of biota can be conserved within it. Since insects comprise most existing biota, they are an important target group for such enumeration efforts. This would require collaboration of a group of entomologists specializing in the systematics of various insect groups.

Vegetation mapping over broad areas of the reserve--Vegetation mapping could be extended to large areas of the reserve via several methods. 1) A simplified, rapid sampling scheme could be employed in order to gather data on tree species composition at a large variety of sites. 2) If the above data are accompanied by detailed information on elevation and slope position, this would facilitate use of GIS methods to predictively model forest composition on unsampled sites; conceivably the use of highly accurate altimeters along with a set of codes for topographic position could facilitate this. 3) Existing data sets could be employed to help this effort; in particular, the very large forest inventory conducted by Charles Vieman and others at SEGEPLAN/UNEPET has not been employed in such an ecological fashion, and holds great potential for such usage.

Additional research topics were suggested in earlier parts of the text.

APPENDIX 14. SOME EXPERIMENTAL DESIGN CONSIDERATIONS

It is essential to involve a professional statistician in designing sampling strategies for the monitoring program. Methods of statistical analysis should also be chosen during the phase of finalizing the design of the program. Here we make only a few comments on experimental design.

Scope of inference

The ability to make valid conclusions from monitoring hinges on our knowing what our valid scope of inference is--i.e., to what population or universe can the results be validly applied or extrapolated? In statistical terms, the *population* is the set of all possible observations of the same kind that can be obtained; in contrast, the *sample* is that set of observations obtained. One population can give rise to many different samples. Some challenges in experimental design are to clearly specify the population of interest, and to ensure that the samples we take are an adequate and unbiassed sample allowing us to confidently characterize the population of interest. For example, if we hope to monitor trends of the bird community of Tikal National Park as a whole, we would need to sample in enough portions of the park to adequately characterize the park as a whole, and in an unbiassed fashion that fairly samples the sites and habitats present within the park. If we hope to monitor the bird community of the MBR as a whole, we would likewise need to monitor enough sites, selected in an unbiassed fashion, to adequately and fairly represent conditions and trends within the entire reserve. Hayek (1994) discusses relevant issues.

Superficial monitoring at many sites or more in-depth monitoring at few sites?

Scope of inference is heavily influenced by decisions about how to distribute sampling effort. A given amount of sampling effort could be distributed among many sites, with minimal effort at each, or at few sites, achieving more adequate sampling of each. For those indicators in which we expect it to be difficult to detect changes from baseline values, due to relatively high levels of natural variability (sampling, spatial, and/or temporal variability) it is probably better to sample more adequately at few sites than to aim for more superficial coverage of more sites. A good example might be the number of amphibians using breeding ponds. We may expect breeding activity to vary enormously through the season, and perhaps between years. Most breeding probably occurs during the rainly season, but even within the rainy season, breeding activity may vary on a day-to-day basis, depending on temperature, weather, water levels, and other factors. In such a case, it is probably better to sample a smaller number of ponds thoroughly, visiting them enough times during one breeding season to have high confidence in the adequacy of sampling, than to visit many ponds only once or twice, thereby risking an incomplete or biassed picture of the population of frogs using those ponds during the season. However, because variability between years is expected to be great, one must sample enough ponds each year to help remove the dominant effect of year-to-year variation.

With attention restricted to relatively few sites, our ability to extrapolate inferences to the entire MBR or some large segment thereof is limited. However, this is unavoidable with limited resources for monitoring. If we sample in, say three study areas that may be considered representative of the MBR, and do an adequate job of monitoring in those three areas, then detection of a similar trend at two or three of these would justify our examining a certain question in greater detail. Hence, monitoring at a few sites may, with luck, serve as an adequate early warning system.

Randomness and independence of samples

The ability to make valid statistical inferences hinges on samples being randomly selected from the target population, and being independent. In reality, in ecological situations, it may be justifiable to sample in a uniform spatial grid across the landscape; Gauch (1982) argues that this is not only acceptable, but sometimes preferrable to truly random sampling. What is not permissible, however, is a haphazard method of selecting sampling sites, with no clear decision rule as to what sites may be sampled. Even worse are methods that allow systematic bias to creep into site selection; an example would be sampling vegetation but consciously or unconsciously avoiding sampling in difficult thickets. Sampling sites should be far enough apart so that they can fairly be said to be independent of one another.

Determining desired levels of Type I and II errors, statistical power, and magnitude of change to be detected

In finalizing design of a monitoring program, it will be important to consider what levels of Type I and II error and statistical power are desired for each aspect of the program, as well as the magnitude of effect to be detectable with these specified error and power values. Type I error is the act of finding an effect where there in fact is none; i.e., the act of judging a result as a significant departure from the null hypothesis when in fact the null hypothesis is true. Customarily, scientists have used alpha (probability of Type I error) = 0.05 as a standard. Type II error (beta) is the case in which an untrue null hypothesis is accepted as true, i.e., of failing to detect an effect which exists. The statistical power of a test is one minus beta, or the probability of correctly rejecting an untrue null hypothesis, i.e., detecting an effect, given the fact that it exists. The power of a test is influenced by the size of effect occurring; a given sampling design and intensity may have high power for detecting a large effect, but low power for detecting a more subtle effect. In general, there is a tradeoff between the size of alpha and beta; decreasing the probability of Type I error increases the probability of Type II error, and vice versa. This makes it important to consider the penalties inherent in each type of error, for the desired results of a monitoring program. For a given combination of alpha and beta levels, power can be increased by increasing sample size, or by increasing the magnitude of effect one is content to detect.

Selection of desired levels of these parameters should be driven by the perceived ramifications of each type of error, and of the urgency of detecting effects of different sizes. Once desired levels of these parameters are in mind, it will be critical to involve a professional statistician in the design process, to calculate alpha, beta, and power levels achievable with different sampling designs, sample sizes, and statistical tests. For this effort, it will be necessary to use actual data generated by the sampling methods in question, in the MBR or a similar situation. Appendix 15 lists potential sources of data from the MBR for use in such calculations.

Various researchers (e.g., Beier and Cunningham 1996) have pointed out that, in the case of monitoring or attempting to conserve an endangered or vulnerable species, it is more important to have a high ability to detect a population decline (i.e., to have high power and low probability of Type II error), than to have a small probability of Type I error. That is, one wants to reliably and sensitively detect population declines, and will accept a probability of "false positive" indications of population decline perhaps higher than the traditional one in twenty. Hence, alpha levels, or probability of spuriously detecting an effect, may perhaps be reasonably set in the range of 0.10 or even 0.20, while beta should be kept reasonably small, perhaps 0.20, so that statistical power, i.e., the chance of detecting an effect that does exist, is 80 per cent. The remaining variable is the magnitude of decline that we wish to detect with the specified power and error risks.

In a simulation with data from cougar track surveys, Beier and Cunningham (1996) found that 50 % population declines were detectable with far greater power and smaller sampling effort than were 30 % population declines. Likewise, in a study of detection rates for bobcats using scent-baited tracking stations, Diefenbach et al. (1994) found it far easier to detect population declines of 32 to 40 % with reasonable power (0.80) than to detect population changes of 24 % and less. These probabilities also hinge on the initial population density, with declines being more easily detectable in a dense population than in a sparse one. A similar pattern, with small population changes being far more difficult to detect than are large changes, is no doubt general in all kinds of population monitoring. In the end, it will no doubt be necessary to strike a compromise between the amount of sampling possible given funding and other constraints, and levels of alpha, beta, power, and magnitude of effect to be detected. The key point here is that it is important to explicitly consider these topics, with the aid of a professional statistician, rather than ignoring them.

Efficient sampling design

Recent papers which give advice on optimal sampling design for avian point counts include Barker et al. (1993), Link et al. (1994), Stillman and Brown (1995), and several papers in Ralph et al. (1995). Skalski (1990) gives a design for sampling which repeats some sites at each sampling period but also includes new sites each time--a design which may facilitate maximization of the number of sites sampled.

APPENDIX 15. POTENTIAL SOURCES OF PRELIMINARY DATA FOR USE IN OPTIMIZING SAMPLING DESIGN

Preliminary data from sampling within the Maya Biosphere Reserve are available, or potentially available, as follows:

1. Bird community (point counts) - D. Whitacre, The Peregrine Fund, 566 West Flying Hawk Lane, Boise, Idaho 83709, USA.

2. Canopy-emergent point counts (raptors, psittacines) - D. Whitacre (see above)

3. Pre-dawn, one-hour point counts (raptors, game birds, primates) - D. Whitacre (see above)

4. Butterfly transects, point counts, and trapping results - Claudio Méndez, USAC/CECON; Nicholas Haddad, University of Florida, Gainesville, FL., USA.

5. Automatic cameras for medium-to-large mammals - Kai Kawanishi, Wildlife Department, University of Florida, Gainesville, FL, or via Dr. Howard Quigley, Hornocker Wildlife Institute, University of Idaho, P.O. Box 3246, Moscow, ID 83843.

6. Tree community composition - Mark Schulze, Department of Biology, Pennsylvania State University, University Park, PA., USA.; other sources include SEGEPLAN (Flores, Petén); ProPetén (Flores, Petén); Steven Gretzinger (Ashland, Oregon); Mauro Salazar (Centro Maya); CATIE (Flores, Petén); IUCN (Flores, Petén).

APPENDIX 16. SOME COMMENTS ON METHODS OF DATA ANALYSIS

Methods of data analysis should be chosen during the phase of designing the monitoring program, as optimal sampling schemes may hinge in part on the kind of analyses anticipated. This should be accomplished through the aid of a professional statistician. The comments below are an eclectic assortment and by no means an adequate consideration of the topic. Though the following comments are phrased in reference to the bird sampling methods given in Appendix 3, they should also apply to the results of butterfly monitoring or other multi-species indicator suites that may be used.

Each of the sampling methods described above generates data that can be analyzed in the same set of ways. For each census, for each bird species, a single datum is used--the number of distinct individuals detected simulaneously at some point during the census. Data from a set of censuses can then be analyzed using (1) parametric methods such as analysis of variance, (2) corresponding non-parametric methods (Mann-Whitney or Kruskal-Wallis tests), (3) contingency-table methods (Chi-Square or variants; "row-mean-score test"), and (4) multi-variate methods such as Principal Components Analysis (PCA), or various forms of Correspondence Analysis ("straight " correspondence analysis = CA, detrended correspondence analysis = DCA, or cannonical correspondence analysis = CCA).

In analyzing bird count data from the MBR, we have mostly avoided use of parametric methods because the number of individuals detected in censuses does not follow a normal distribution (a required assumption for use of parametric methods). Most detections per census are either 0, 1, or 2, with occasional larger values. Non-parametric methods are more appropriate, but in fact, these data distributions are quasi-categorical in nature, and so contingency-table methods are yet more appropriate. However, we have found very little difference in the results of Mann-Whitney or Kruskal-Wallis tests (non-parametric) and those of the "row-mean-score" (categorical) test. Because the latter is generally not familiar to many researchers, we suggest that use of the much more widely known and simple Mann-Whitney and Kruskal Wallis tests is adequate. We use these tests in a species-by-species manner, comparing the results of a given species across habitats or other comparison units. When tables of results for a large number of species are presented, one should then adjust the statistical rejection region so as to maintain true table-wise probability levels at the stated nominal level (usually $p = 0.05$). For this we recommend the sequential Bonferroni procedure described by Rice (1989); this test maintains maximal statistical power, unlike some other Bonferroni tests that are needlessly conservative. To test for trends over years, appropriate statistical tests must be selected during the design phase. We do not discuss such tests here, except to comment that repeated census of the same sites introduces auto-correlation, which will affect the choice of analytical methods.

Verifying indicator values of species and community composition

The multi-species data generated by the sampling methods advocated here lend themselves extremely well to use of the multivariate methods listed above (PCA, DCA, etc.). During each point count or other sampling event, one obtains data on a large list of species, which collectively reveal information about the biotic community at that point in space far more adequately than do the census results for any one species. Subjecting data from a large number of point counts at different points in space to an ordination by PCA or DCA is an excellent way to reduce the existing complexity to two dimensions, making them comprehensible through visual inspection of the resulting XY plots. Whether or not such an approach is used for routine analysis of monitoring results, it is an invaluable aid in evaluating the indicator properties of species and community composition. Hence we strongly advocate the use of this approach during the phase of designing and refining the monitoring program.

Routine data analysis using multivariate methods

Once indicator properties of species and overal community composition have been determined, there are at least two ways to go about routine analysis of monitoring results. One way to monitor for change over time would be to (1) ordinate initial data (year 1) via PCA or DCA; (2) retain this ordination file, and (3) after incorporating subsequent data from re-censusing the same points in a later year, (4) re-run the same ordination procedure, but with the new samples as "inactive" samples. In this way, the new data would not be used to change the initial ordination, but only to situate the new samples within the original ordination space. That is, the placement of the original samples within "ordination space" should be identical to what it was in the original ordination, and the new data from each sample would be plotted within the original ordination space. One can then visually inspect the position of each new sample at a given point in space with respect to its original position in the ordination plot. Of course, no sample would be expected to fall in the exact same position as earlier, due to various sources of randomness and sampling variability. However, conducted repeatedly, this should reveal whether certain samples are consistently moving in a certain direction with regard to community composition and structure. For example, a group of point count sites that are being progressively converted from mature forest into a mosaic of slash-and-burn agricultural fields should steadily shift in the direction of those samples in the original ordination that were taken in slash-and-burn fields. Similarly, samples in an area that is being increasingly thinned by logging or fuelwood cutting, should likewise shift toward the samples originally taken in such sites. For characterizing trends at sites, such a multivariate approach should be more powerful and reliable than relying on the results for any single species. Alternatively, one could examine trends for individual species, and then somehow characterize the overall trends demonstrated by that collection of species; this would allow one to avoid use of multivariate methods. Useful advice on the multivariate methods mentioned above may be found in Gauch (1982), ter Braak (1987, 1988), Jongman et al. (1987).

Routine data analysis using a simple Index of Biotic Diversity

Fore and Karr (1996) strongly argue against use of multivariate methods in routine analysis of monitoring data. Rather, they advocate construction of a simple Index of Biotic Integrity for each indicator complex. In this approach, once one has discovered from initial research the ecological significance of the presence, absence, or abundance of many species, one can construct a simple scoring system to generate a value or series of values that reflects the relative departure of the site in question from the pristine state. For example, a large positive number might be awarded due to the presence of a species that is restricted to undisturbed forest, and a large negative number might be awarded for species that reliably indicate pasture habitat; species that are habitat generalists would receive no or small scores, and would not much influence the score for the site, as they have little indicator value. Such an approach has been used at least for fishes and aquatic invertebrates (Karr 1981, Karr et al. 1986, Kerans and Karr 1994, Fore and Karr 1996), and should function very well for birds, insects, amphibians, and trees of the MBR. This approach has the advantage of extreme simplicity, once the initial studies have been conducted and indicator values assigned. We strongly advocate the use of this approach for routine analysis of monitoring data. Initial efforts toward formulation of an avian Index of Biotic Integrity for the MBR are reported in Whitacre (1997).

Other methods

The U.S. Environmental Protection Agency's EMAP program recommends use of cumulative distribution functions as a means of portraying (with a stated probability) the proportion of a resource class which meets a certain criterion (e.g., exceeds a minimal acceptable standard). According to Alexander and Barnard (1994b), many monitoring programs around the world use this method in presenting results of monitoring. It would be worth investigating this method and its utility.

Diversity indices

It is advisable to largely avoid attempts to represent biological diversity through the use of single-number diversity indices (e.g., Shannon-Weaver, Simpson's, etc.). Except for specific cases where such indices may be appropriate, other approaches are better as they retain much more information about the biological system than do these indices (Hurlbert 1971). As argued earlier, it is more appropriate to focus on ecological "integrity", which focuses largely on *which* species are present (Karr 1991, Angermeier and Karr 1994) rather than simply on abundance patterns of anonymous species, as in the traditional diversity indices. The composite Index of Biotic Integrity described above is far more useful that are diversity indices.

APPENDIX 17. RECOMMENDED STANDARDS FOR COLLECTION OF LOCALITY DATA

For all monitoring efforts, it is essential to obtain reliable locality data allowing unequivocal relocation of the same point at a later date, even years later. We recommend the following:

1. All sample points must be tied in, at least by a pace and compass map or odometer reading, to a readily identifiable geographic feature, which must be accompanied by detailed latitude and longitude.

2. Such reference points may be road junctions, distinct features of roads (hills, curves), bridges, terrain features (hills, swales, creeks, rivers, aguadas), villages (distance from a recognizable point in the village should be indicated, such as a school, church, canche de futbol, etc.)

3. GPS points should be taken whenever possible at main reference points, and if convenient, at sample points as well.

4. Each sampling complex that is distant (several km) from a truly recognizable reference point should have a nearby GPS point (within 200 m) associated it, even if this entails considerable effort (i.e., climbing a tree to take the reading).

5. Individual sampling points should be tied into the latter by means of pace and compass maps, using known length of pace, and a specified "kind" of compass "North".

6. All sample points should be indicated on detailed sketch maps that facilitate their relocation, and on 1:50,000 topographic maps.

Kinds of North:

Topographic maps in Petén indicate three kinds of north:

1. Magnetic north.
2. True north.
3. Norte de Cuadrícula.

We recommend use of Norte de Cuadrícula throughout the monitoring program, but in any case, the kind of north used should be indicated in field notes and data sheets, using at minimum, the abbreviations N c (norte de cuadricula), N v (Norte verdadera), and N m (Norte magnetica).

It should be noted that the deviation of magnetic north from true and cuadricula north changes slowly and predictably over time, so that the appropriate declination differs slightly each year. This may be calculated from information given on Petén topographic maps sold by the Instituto Geográfico Militar.

APPENDIX 18. METHODS FOR HABITAT CHARACTERIZATION

All field sampling should be accompanied by a standardized description of habitat at the sampling site. Likely it will prove necessary to use two distinct formats for habitat description--a very basic, categorical description in some cases, and a more detailed description in others.

Less detailed description

For sites visited only briefly, for example, where mammal scent/track stations are put out for a single night, detailed habitat characterization will not be practical. For cases of this nature, a data sheet should be created, which lists and describes discrete habitat "types". The investigator would then simply indicate which of these habitat "types" is applicable to the sampling site. Habitat "types" should be established carefully so as to provide adequate descriptions of different kinds natural and human-modified landscapes.

More detailed description

For sites where more detailed and lengthy sampling is conducted, it will be important to more fully characterize the habitat. For this, we suggest the following for forest habitats.

a. Sample 1/10 acre (0.04 hectare) plots; these can be either circular, or rectangular. Rectangular plots of 10 m width and appropriate length (roughly 40 m, but precise calculation should be made) are quicker to establish and to sample; we recommend that this method be used. Within each of these:

b. Identify and record diameter at breast height (dbh) of all trees greater than 3 cm dbh.

c. Measure average, lowest, and greatest height of upper canopy surface at three points along the transect (center and near each end). Use a Haga altimeter or other device for this; otherwise, estimate height in 3 m increments.

d. Indicate topographic position, using pre-established categories.

e. Measure terrain slope and aspect.

f. Indicate degree of human disturbance using a simple categorical system.

g. Indicate distance from main road and score magnitude of road.

h. Indicate distance from trail and score magnitude of trail.

g. Score soil texture at the plot center via a simple, manual texture method.

h. Score degree of rockiness of the site and of the soil.

i. Canopy cover should be scored via five readings with a canopy densiometer, at 10 m intervals along the transect.

j. Ground cover (green vegetation $<$ 1 m height) should be scored via 25 or more sightings (hit/miss) with a sighting tube with cross hairs, at 1 m intervals along the transect.

k. Density of guano (*Sabal morrisiana*), escobo (*Cryosophila argentea*), and cordoncillo hoja-fina (*Piper cf. psilarachis*) in the understory should be scored via a categorical system; this reveals much about forest type.

APPENDIX 19. RECOMMENDED STAFFING AND STRUCTURE FOR A BIOTIC INVENTORY/MONITORING UNIT WITHIN CONAP

1. The need for establishment of a regular patrol program

The need to frequently patrol many areas of the reserve is self-evident. In addition to guarding against prohibited activities, such a patrol program would facilitate realization of monitoring activities by resource guards. Establishment of reliable radio communication would greatly facilitate safe patrolling in the more remote areas, and enhance efficiency and responsiveness overall.

2. Proposed organization of monitoring efforts and personnel

We assume that CONAP should be the entity responsible for coordinating the monitoring program, because CONAP is the agency that will mainly use the information collected. We suggest the creation and staffing of the following positions within CONAP Region VIII:

1. Chief of Inventory and Monitoring Program--This person's primary tasks should be to devise the details of the monitoring program (with advice from a monitoring committee; see below), to ensure adequate training and supervision of resource guards in their monitoring capacities, to ensure that data collected by resource guards and others taking part in monitoring is turned in regularly to the Chief of Monitoring Data Base, and to ensure quality control of data through appropriate training and oversight of personnel taking part in monitoring. We anticipate that the chief of the inventory and monitoring program will be in frequent contact with the chief of vigilance and patrol. Patrol teams should routinely consult with the monitoring chief each time before and after they go into the field. They should enter the field armed with the most recent patrol report from the areas where they are going, and with a list of things to check out. The chief of vigilance should consult closely with the monitoring chief in planning where control posts or other infrastructure are needed, as well as in planning new patrol routes or changes in existing ones. Summary reports of trends should be prepared quarterly, with an annual report distributed outside the agency; the program chief should add interpretation and analysis to the data summaries provided by chiefs of the tabular and GIS databases.

2. Chief of Tabular Database--This person's primary task should to be to manage non-GIS data, analyze it, and prepare periodic reports of trends in the data. Summary reports should be provided regularly to the program chief. This person should be responsible to report any shortcomings in data quality to the Chief of the Monitoring Program, who should make any necessary changes to ensure adequate data quality.

3. Chief of Geographic Information System - This person would maintain a functional GIS laboratory and would manage all activities thereof; s/he would prepare periodic analyses of spatial aspects of the biota, threats, and monitoring and patrol activities.

4. Data entry technician--This person would assist in data entry in both the GIS and tabular data bases.

5. Field personnel - The number of field personnel will hinge on the final formulation of the monitoring program. Monitoring field crews should consist of teams of two or three persons, equipped with a vehicle, camping equipment, and all necessary sampling equipment. A modicum of monitoring could be accomplished with a single field crew, but much more could be accomplished with two or three. Access to boat and motor will also be required in certain areas.

3. Scientific advisorial committee

We suggest that the monitoring program be advised by a committee composed of several scientists with relevant experience.

4. Data management

In order for monitoring data to be useful in decision making, it must be maintained in a readily accessible and usable form, with essentially zero chance of data loss. Further, the initial steps of data reduction and analysis must be regularly and "automatically" performed; i.e., those wishing to trace the ecological status of the reserve should not have to immerse themselves in raw field data. Rather, data should be analized and summary reports produced and disseminated yearly.

The data base and data management system should be carefully designed prior to beginning a full-scale monitoring program. A critical step is to prescribe standards and protocols for archiving and back-up of both original data sheets and of data once it is entered into the data base, in both electronic and hard-copy formats. Loss and misplacement of library documents is a chronic problem in many governmental institutions, and CONAP is probably not immune to this problem--hence the importance of this step.

5. An information management system for CONAP

Apart from the issue of managing and using monitoring data, another need exists within CONAP, to provide the ability to make use of scientific information in management of the MBR. A great deal of biological information on the MBR is already available, and is probably not being utilized to maximum advantage by CONAP, for lack of a mechanism by which such information is taken into account in decision-making. To mount a concerted monitoring program when existing biological information on the reserve is not being fully used is of questionable wisdom.

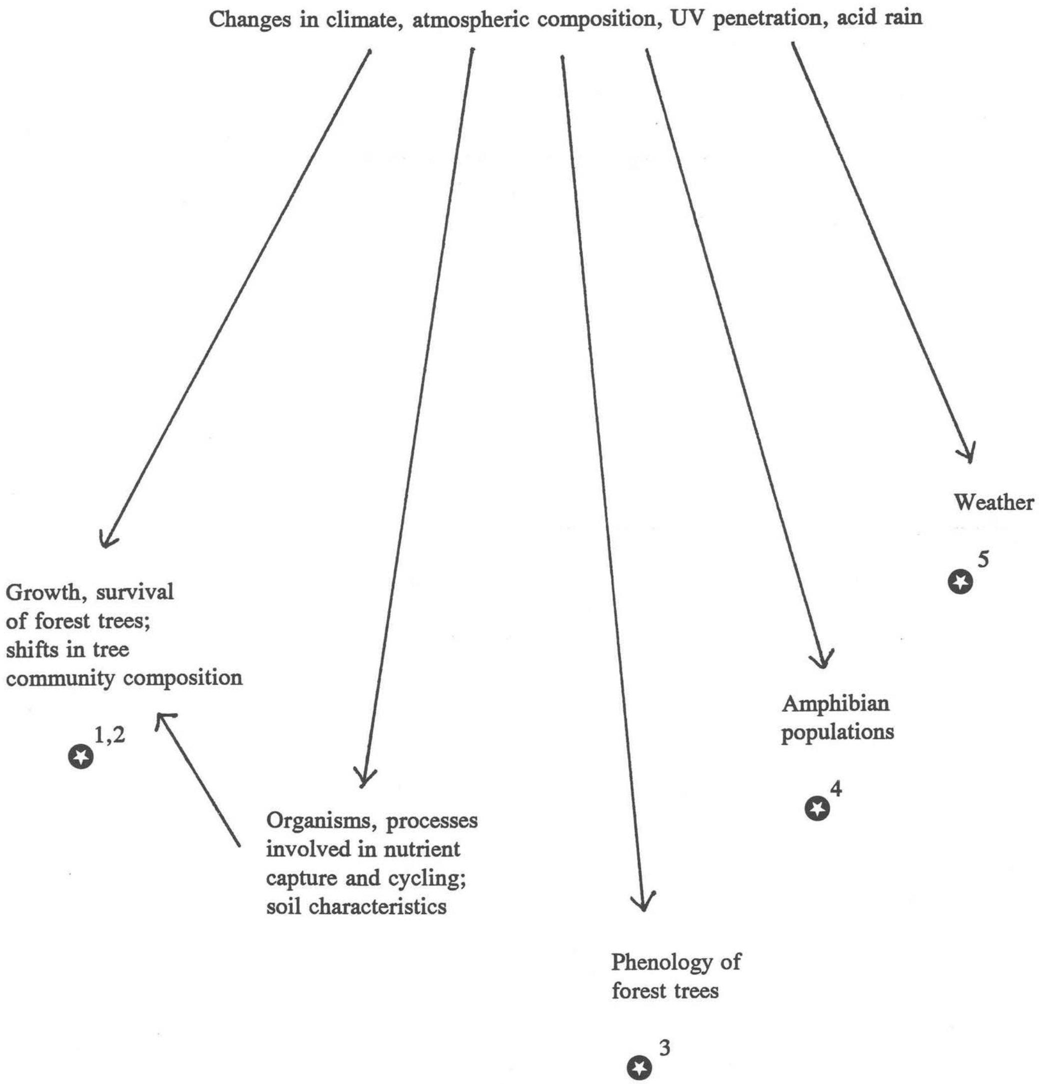
Hence we suggest CONAP create and fill a staff position for a "chief scientist" or something similar. This person would have strong academic training in biology, ecology, wildlands or wildlife management, or a related field, and would be responsible to collate and assimilate existing biological information on the MBR. A librarian would be responsible for maintaining such information sources as a permanent library within CONAP. The chief scientist's job would be to fully assimilate the information available on the biotic resources of the MBR, and to educate his/herself continually on issues relevant to reserve management in general, in order to advise the Secretaria Ejecutiva in decisions regarding management of the MBR.

6. Turning monitoring results into conservation action

Little will be achieved by a monitoring program if results are not turned into effective conservation action. One could say that the greatest need for management of the MBR is simply to create an effective mechanism for action. The monitoring framework suggested here should create a continual flow of information to the monitoring center; we must ensure that this information is rapidly and routinely translated by CONAP Region VIII and CONAP central into actions that protect and effectively manage the Maya Biosphere Reserve.

In periodic reports summarizing the results of monitoring, the chief of monitoring should highlight areas of rapid change and where other notable occurrences have taken place or appear to be developing. He/she should draw the attention of the regional director and the MBR coordinator to these areas, so that they can decide upon courses of action to take with respect to these areas and phenomena. It is worth emphasizing the importance of rapid response during initial stages of change. For example, when remote sensing reveals new areas of rapid invasion, it is essential that CONAP makes it a high priority to respond promptly, as it is much easier to prevent invasion than to move invaders out of the reserve once they are there.

Figure 1. Conceptual model for monitoring effects of global or regional climatic or atmospheric effects.



Monitoring methods: ✪

1 permanent plots with marked trees

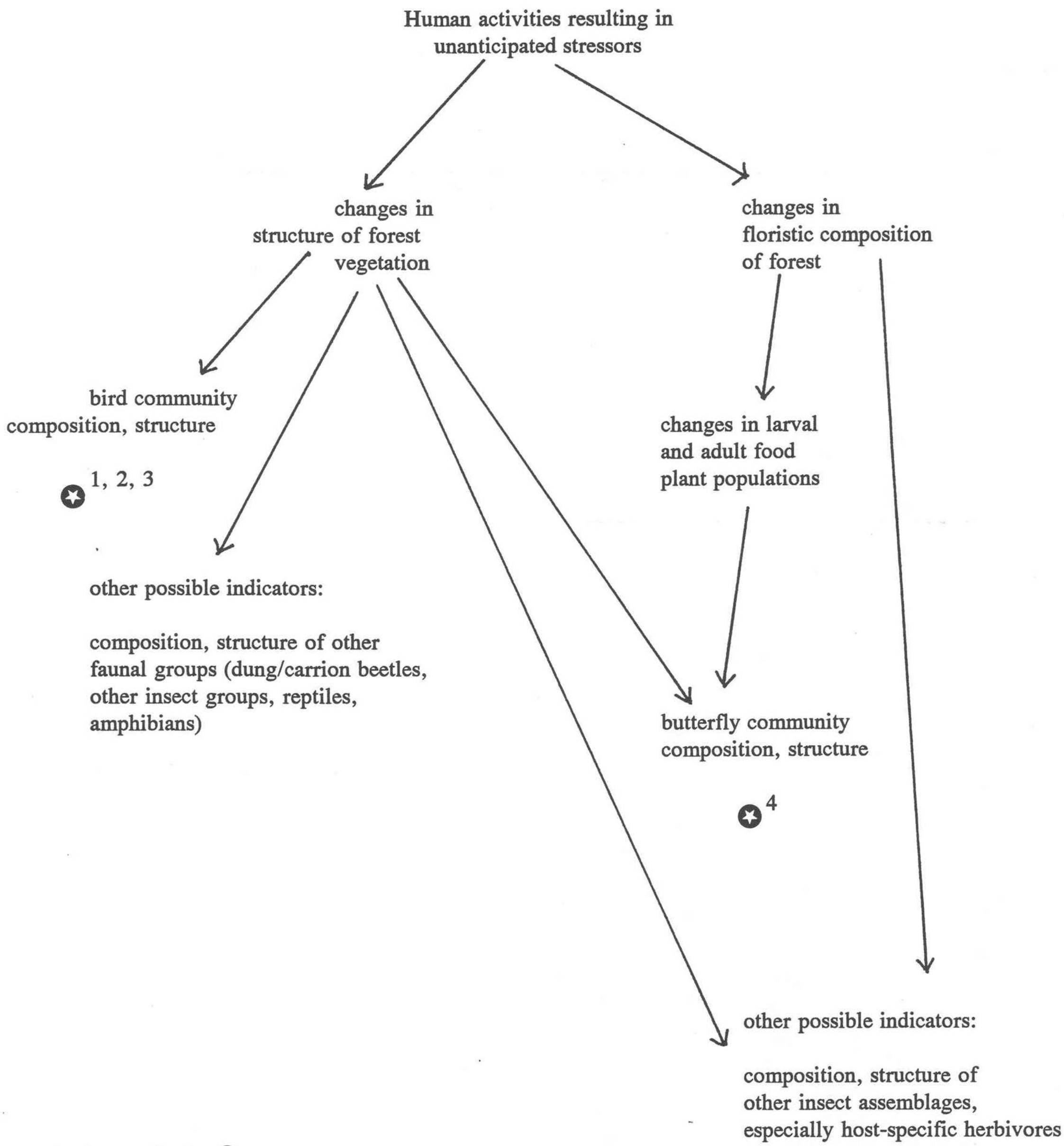
2 seedling regeneration plots

3 phenology plots for forest trees

4 frog census (at breeding sites, possibly visual transects and auditory point counts or transects)

5 collate and analyze data from weather stations in and near MBR

Figure 2. Conceptual model for monitoring local, within-habitat effects of habitat alteration.



Monitoring methods: ✪

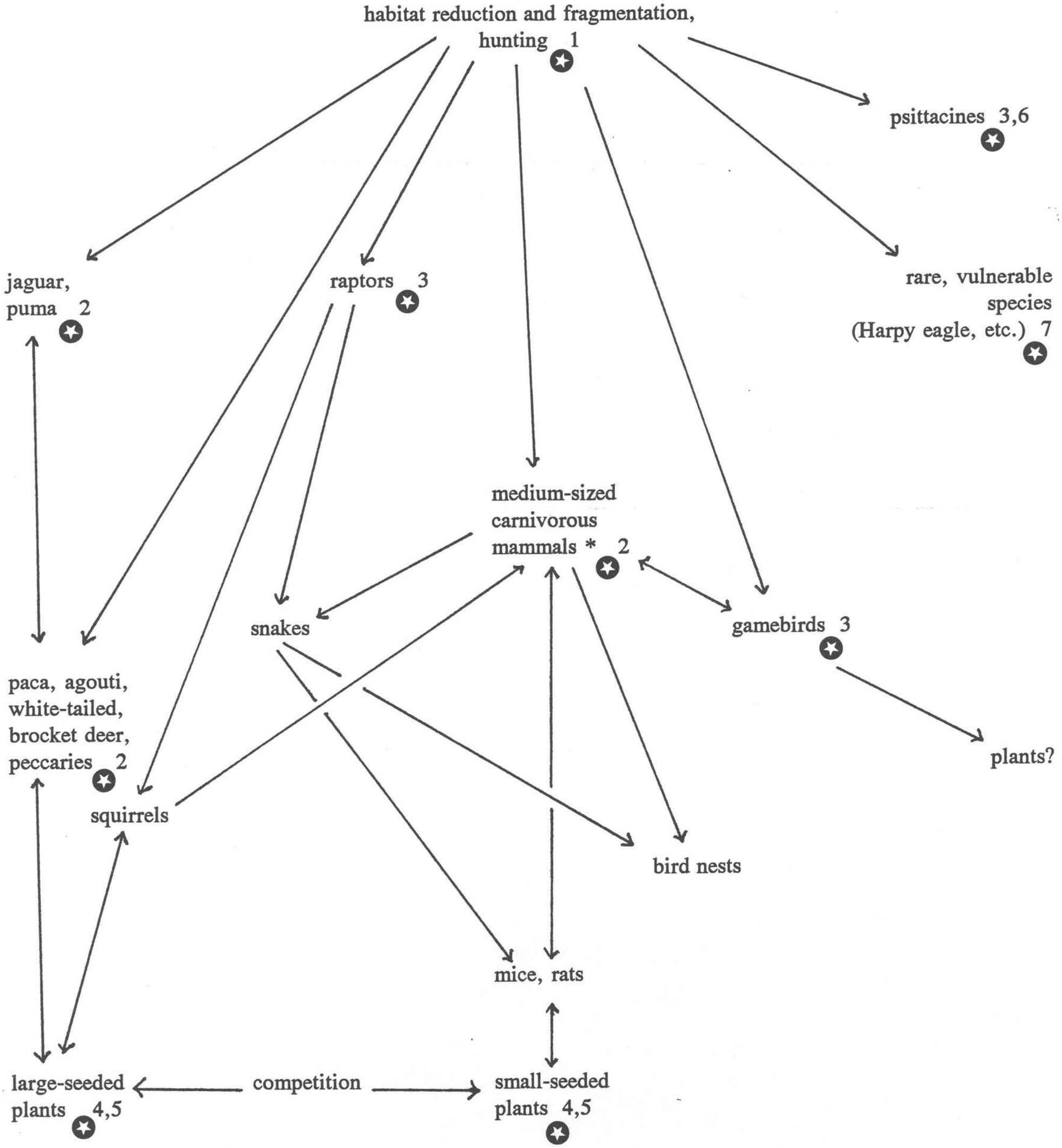
1 5-10 minute point counts (for 90 + bird species)

2 canopy-emergent 2.5 hour point counts (for raptors, psittacines)

3 1-hour pre-dawn point counts (for game birds, raptors)

4 visual census, baited traps, voucher collection

Figure 3. Conceptual model for monitoring ecological effects of factors that may alter populations of area-sensitive species.



Monitoring methods: ✪

1 satellite imagery
2 automatic cameras, scent-baited tracking sites
3 canopy-emergent and pre-dawn point counts
4 permanent plots with marked trees
5 seedling regeneration plots, exclusion plots
6 monitoring of macaw nesting areas
7 resource guard reports, investigate reported sightings

* ocelot, margay, jaguarundi, gray fox, tayra, skunk, coati, raccoon, ring-tailed cat, weasel, etc.