Conceptual Frameworks for Monitoring of High-altitude Andean Ecosystems

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Abstract—*The Ecuadorian government and its partner organizations in the international conservation community share an interest in developing monitoring programs for Andean protected areas to help support management for recreation, education, and ecological sustainability. To accomplish this goal, the U.S. Agency for International Development and the Department of the Interior are providing assistance to establish a system of ecological monitoring. Assistance was focused on Parque Nacional Cotopaxi, a protected area centered on a 5911m active stratovolcano and an ecosystem dominated by the paramo vegetation association. A number of issues complicate the development of monitoring and management systems for such protected areas. Among these are uncertainty about the roles and interactions of ecosystem drivers, the relative importance of various anthropogenic factors, and a need for clarity about how individual protected areas function within larger ecological and socioeconomic contexts of Andean landscapes. Changes in factors of management interest can be viewed as progression along, or deviation from, pathways of ecological succession. A simple conceptual model integrating physical and anthropogenic factors has been developed to help describe a basic Andean successional template. Elevation gradients are well-established as fundamental ecosystem determinants in montane ecosystems throughout the world. Further articulation of this concept makes it clear that proximity to volcanic activity in space or time can be considered a primary driver. Similarly, spatiotemporal proximity to glaciation is another clear determinant of successional status. In addition to physical ecosystem factors, human perturbation is proposed as a cause for deviations (altered trajectories, novel stable states or cycles) from "normal" successional gradients. Monitoring of Andean ecosystem status and trend should be designed and implemented taking into account this physical system/perturbation template. In addition to stratification along lines of zonal and azonal ecological communities, sample design for monitoring ecosystems should first be stratified along lines of volcanic and glacial disturbance, as well as human perturbation.*

Introduction

The Ecuadorian Ministry of the Environment and the US Agency for International Development are working toward the development of a system to support the conservation and beneficial uses of recreation, education, and ecological scientific understanding at Parque Nacional Cotopaxi (PNC) and other Andean protected areas. There also is interest in the development and establishment an ecological monitoring system for PNC.

- Monitoring system development is crucial because:
- PNC is a magnet for domestic and foreign visitors; plans for future ecotourism are likely to increase visitation pressure.
- No basic inventory of PNC's resources has been conducted.
- Changes to PNC have accelerated over the last 50 years.
- Reports on PNC resources are available, but also problematic because many of the reports are not readily accessible to managers in Ecuador; past investigations have also employed different methods making comparison and integration difficult.
- There is a need to determine status and trends for PNC ecosystems, flora, and fauna.
- Patterns of ecological succession have not been identified, nor have potential positive or negative deviations from "natural" successional trajectories.

- Stream and lake systems in PNC are not well-understood with respect to their value as habitat for wildlife and aquatic biota, water quality, or water supply
- Interactions of ecological and anthropogenic factors through time have not been described.
- Ecological conditions within PNC need to be better integrated with past and future volcanism affecting the Cotopaxi region.
- PNC administrators do not have information needed to deal with Park visitation, use of Park resources, and adjacent land uses.
- It is unclear how PNC fits within the larger context of Andean ecosystems, as well as surrounding land uses, cultures, and economies.

In the face of such extensive needs, funding to implement a system of PNC monitoring is in short supply and the Park staff is burdened with ongoing commitments that preclude implementation of a viable monitoring program. Given similar situations in many of the protected areas of the Andes, it is important that monitoring program development and implementation be initiated using technologies that are inexpensive, simple, and robust with respect to the information yield for a given level of effort. However, this does not imply that the easiest or most obvious monitoring protocols should have the greatest priority for implementation. A step-wise process for monitoring program development (Noon 2003) becomes critical when implementation efficiency is so important. A key initial step in monitoring protocol development is agreement about system processes and resource states. Such agreement is best reached through the development of system conceptual models.

Monitoring Design Process

Monitoring at Andean protected areas should not planned or conducted independently at individual sites. A number of resources are available for the development of a coordinated ecological monitoring system for such areas (Busch and Trexler 2003, Elzinga and others 2001, Feinsinger 2001).

A useful way to view monitoring is in the context of an adaptive assessment, or adaptive ecosystem management, framework (Holling 1978). This type of framework is helpful in showing how monitoring can influence management actions, but it is also essential to understand that monitoring data alone are not sufficient to complete the adaptive management cycle supporting productive natural resource decision making. Proper analysis and evaluation of data from a variety of sources is critical, as are formats for communicating and developing planning options to put well-founded alternatives in front of natural resource managers (Palmer 2003). Data management and the conversion of data into useful information and knowledge are important steps in a properly functioning adaptive management process. For monitoring of the system of Andean protected areas, including PNC, it is important that the responsible organizations develop sustainable networks capable of aggregating, storing, and distributing data for analysis and report writing.

Various versions of a stepwise process to develop monitoring plans have been presented. In general, approaches used in different monitoring programs are comparable with each other utilizing a step-wise process similar to that recommended by Noon (2003):

1. Specify goals and objectives
2. Characterize system stressors
3. Develop conceptual models of the system
4. Select monitoring indicators
5. Establish sampling design
6. Define response criteria
7. Link monitoring results to decision making

For PNC and related Andean protected areas, steps 1 and 2 were at least partially articulated in advance by policy makers. In spite of this, the development of scientifically-valid monitoring plans often requires a re-articulation of goals and objectives using the principles of the technical disciplines involved (Reeves and others 2004). Meetings with Ecuadorian scientists and PNC management staff helped to reaffirm goals and objectives and characterize system stressors in an ecological context. Using information from the literature, from field visits to Andean protected areas, and from the aforementioned meetings, a first-generation conceptual framework for monitoring is proposed here. Agreement about basic ecosystem stressors and drivers permitted the derivation of a preliminary set of indicators and sampling design (Busch and Jorgenson 2004). Although much has been accomplished, all of these steps, particularly those toward the end of the sequence, should be revisited to evaluate what additional measures will be necessary to assure the success and sustainability of a monitoring program for PNC and related Andean protected areas.

Conceptual Framework

Monitoring in the Cotopaxi area must be integrated within the context of neighboring land uses as well as monitoring at greater spatial scales. Although monitoring in North American systems has not enjoyed total success in integrating information between fine and coarse scales, paradigms for making such connections have been derived (Trexler and Busch 2003). Such models can be helpful in thinking about how monitoring at a single unit such as PNC, may contribute to monitoring in ecologically-related parts of a region (for example, The Nature Conservancy multi-national Condor Bioreserve), or throughout Ecuador's system of protected areas.

The missions of individual Park units and systems of protected areas are diverse. Consistent with this, the needs for monitoring are similarly diverse (fig. 1). There may be a species or community of interest (for example, a keystone, umbrella, or emblematic species) that is considered to be the monitoring focus. Alternatively, aggregations of species, as indicated by various measures or estimates of biodiversity, may be the primary interest. Given adequate understanding or assumptions about environmental parameters that support species requirements, there may be a focus on habitat, or there may be understanding and interest in various physical dimensions adequate to catalyze an ecosystem-based approach. Brainstorming ("Lluvia de Ideas") meetings with Ecuadorian specialists about potential needs for PNC and related areas produced a list of potential categories incorporating important processes, drivers, stressors, and resources:

- Vegetation and plant succession
- Climate change, C & N cycles, photosynthesis, ET
- Invasive and exotic species
- Rare or biotically rich environments (wetlands, etc.)
- Hydrology and water quality
- Visitor use and abuse
- Threatened and endangered species (listed species)
- Land use – fire, grazing, forest management
- Social factors (park visitation and indigenous cultures)
- Endemic, flagship, keystone species
- Economic factors (ecotourism and extractive economies)

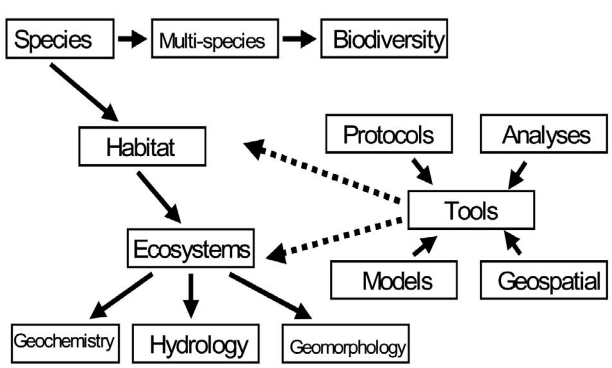

Figure 1. Potential dimensions of interest for monitoring ecosystems; tools for making monitoring efficient and integrating across dimensions.

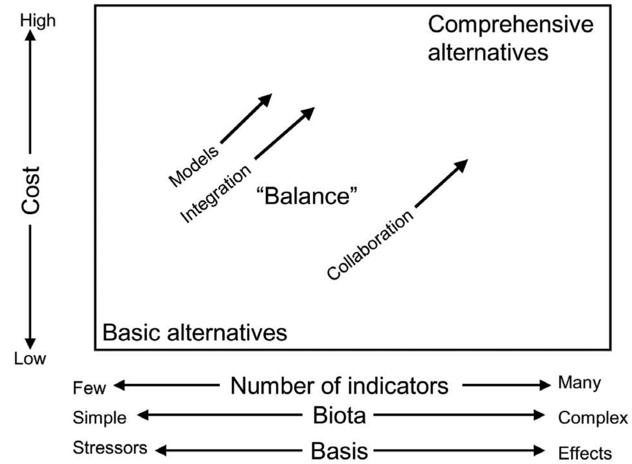

Figure 2. Concept for outlining monitoring alternatives at varying levels of complexity and cost.

As can be seen from lists such as this, monitoring interests in the Ecuadorian system of protected areas are many and varied. Caution must be exercised to temper the expectations about the level of monitoring that can actually be implemented. A concept for developing monitoring alternatives ranging from those that are low in complexity and cost to those of increasing sophistication is presented in figure 2. Obviously, the information yield is greater as more staff and financial resources are added to the monitoring program. However, another important implication is that there are a number of analytical mechanisms for making monitoring more efficient and effective, potentially at relatively little additional cost. Crucial to the development of such efficiencies is the growth of collaborative mechanisms between those with a stake in field-level sampling and those possessing the capability and interest in aggregating, archiving, analyzing, modeling, and communicating based on the information collected.

Changes in factors of management interest can be viewed as occurring upon a physical ecosystem template. For example, elevation gradients are well-established as fundamental ecosystem drivers in montane ecosystems throughout the Andes (Humboldt and Bonpland 1807). Further articulation of ecosystem drivers in ecosystems of the Ecuadorian Andes is clearly possible. From our observations at PNC and neighboring Andean systems, it is proposed that the proximity to volcanic activity in space or time is one primary driver (fig. 3, top). Relatively recent volcanic activity at Volcan Cotopaxi has affected PNC ecosystems more profoundly than those at nearby montane systems where volcanic activity is spatially or temporally more distant. Proximity to features of intense volcanic activity (e.g. lahars) also has clear effects on successional status of sites within PNC. Glaciation is

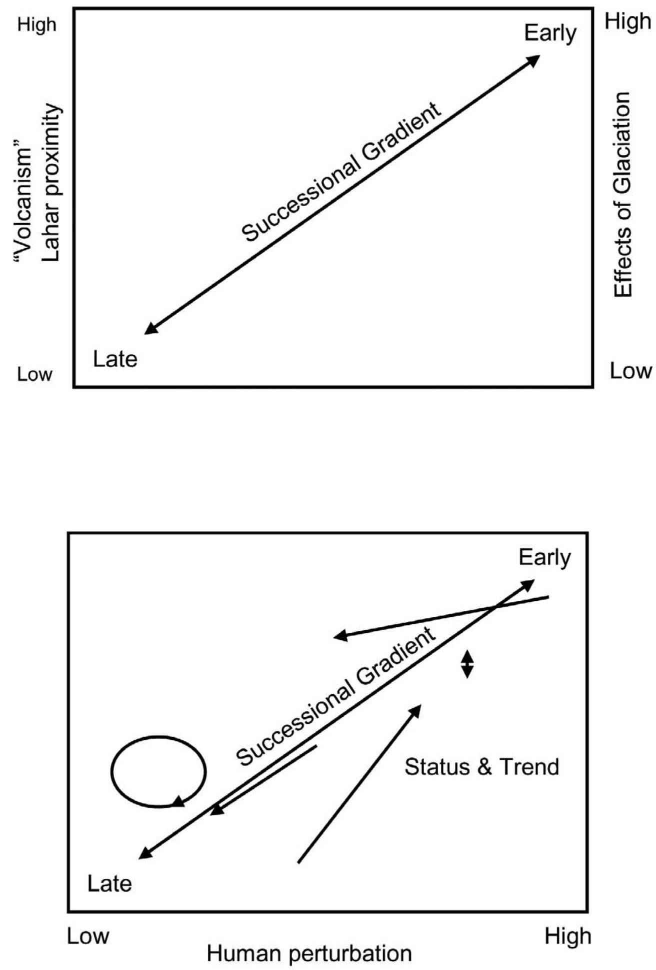

Figure 3. Monitoring of ecosystems in relation to successional gradients. Status and trend of ecosystem as successional trajectories with proposed "drivers" for Andean ecosystems

proposed as another important dynamic in such systems. Similar to volcanic activity, the proximity to active glaciers, morainal deposits, etc. in space or time also appears to be a clear determinant of successional status.

In addition to physical ecosystem factors, human disturbance is proposed as a determinant of ecosystem successional status (fig. 3, bottom). However, whereas volcanism and glaciation can generally be viewed as primary drivers of other ecosystem processes in more or less "natural" patterns, perturbation of ecosystem processes by humans is likely to be a cause for deviations (altered trajectories, novel stable states or cycles, etc.) from normal successional gradients. While the focus of this model is ecological, fuller incorporation of a perturbation axis into the conceptual framework for PNC and related Andean protected areas will require the development of parallel socio-economic systems of factors and drivers.

Conclusion

Monitoring of Andean ecosystem status and trend should be designed and implemented taking into account a physical system/disturbance template. In addition to stratification along lines of Andean zonal and azonal ecological communities (for example, puna, paramo, pajonal, mattoral, quebradas humedales, lagos, etc.), sample design for monitoring ecosystem subsystems should first be stratified along lines of volcanic disturbance, glaciation, as well as human perturbation. Once a basic level of understanding has been developed about cause and effect relationships between the most important Andean ecosystem stressors and their ecological consequences, selection of the most effective and efficient monitoring indicators will be possible.

Acknowledgments

Fruitful discussions with a number of specialists who have studied Andean ecosystems and society were essential to our work. We especially wish to thank Janet Jorgenson and Marc Weitzel (U.S. Department of the Interior, Fish and Wildlife Service); Darwin Hernandez, Marco Encalada, and Rocio Bastadas (Corporacion OIKOS); Rocio Cedeno (U.S. Agency for International Development), and the staff of Parc Nacional Cotopaxi.

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