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Biological Monitoring in the Amazon: Recent Progress and Future Needs

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RICH, LARGE, AND THREATENED AREAS, SUCH AS THE AMAZON, POSE A DIFFICULT CHALLENGE FOR BIOLOGICAL MONITORING. Glaring threats such as deforestation, hydrological disturbance, and climate change create an urgency to monitor the right variables now. Being so large, the study system can be approached at a multiplicity of scales, raising monitoring design problems. Furthermore, the extraordinary biological richness requires that we monitor things that are poorly known or hard to identify, posing problems for data collection. We summarize some recent progress and future needs for the handling of threats, scale, and richness by biological monitoring programs in the Amazon. These three issues address three stages of the conception of a monitoring program: the root definition of *why* and *what* to monitor based on the target threat; the choice of a spatial scale of work that will guide development of a sampling design; and the overcoming of practical difficulties imposed by extraordinary species richness.

THREAT-ORIENTED MONITORING

The Amazon is subject to various threats, including hunting (Peres & Lake 2003), the replacement of forest by monoculture (Fearnside 2001, Nepstad *et al.* 2006), widespread habitat destruction (Skole & Tucker 1993; Laurance *et al.* 2001, 2002), and global climate change (Lewis 2006). The first step of a monitoring program should be the identification of a threat whose consequences we intend to monitor. Rather than measuring indicators that broadly reveal some form of biological well being, one should start by deciding precisely what the indicators are meant to indicate. Leaf-litter depth will not be the best indicator of basin-wide forest loss; and the monitoring of primate species richness says nothing about the effects of overfishing. To be most effective, monitoring must be threat-oriented.

For example, the *Amazonas* state program for monitoring biodiversity and natural resource use in protected areas (ProBUC), created in 2006, was targeted at pre-defined threats (Marinelli 2007). A group of ecologists, managers, and specialists on the taxonomy of different groups, meeting under ProBUC's sponsorship, identified wildlife poaching, overfishing, and illegal timber extraction as key threats and discussed strategies for assessing them. The good news is not the particular choices they made, but that a monitoring scheme has been rooted on a pre-defined set of problems that will be targeted by data collection in the field. Another example of clear targeting, the industry-funded PIATAM project, monitors environmental impacts of the transportation of oil and gas along the Amazon River (PIATAM 2007). PIATAM started in 2000 and is in the process of refining sampling designs and expanding its operations. PIATAM and ProBUC's well-funded focus on threats is novel, both in the Amazon and the broader monitoring context (Yoccoz *et al.* 2001). Their potential effectiveness holds relevant lessons for the future.

Data from nontargeted programs that are already in place can be extremely useful (Buckland *et al.* 2005, Loh *et al.* 2005) but if we are to design new programs, effectiveness will come with a well-defined target (Nichols & Williams 2006). Threats may be hard to define because of synergies among them; causality between threat and monitoring variables is often difficult to establish. System changes, such as global warming and hydrological disturbance have particularly elusive consequences. These difficulties raise a concern:

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will threat-oriented programs limit our ability to detect unforeseen problems? No, because the unforeseen is, by definition, unknown. And that which is not known cannot constitute a criterion for the quality of a monitoring program. That is why there is no telling which type of program does a better job of detecting surprises. For example, the Waterfowl Breeding Population and Habitat Survey of the U.S. and Canada was designed to inform habitat and game management decisions. Despite the narrow focus on harvest regulation of a small number of species, the survey was perfectly capable of detecting an unforeseen decline in the population of pintail ducks, *Anas acuta* (Wilkins *et al.* 2006). On the other hand, the North American Breeding Bird Survey, arguably the most extensive unfocused program ever implemented, failed to identify convincing population trends for species that were known to be in decline from alternative lines of evidence (Sauer *et al.* 2005). Readiness for the unknown is a respectable goal, but there are plenty of foreseeable problems that need urgent addressing. We propose that every new monitoring program should consider at least one target threat. Its assessment should guide program design.

EFFICIENT DESIGN—ONE SCALE AT A TIME

Even in the absence of a target threat, one makes choices about monitoring design, chief among them the choice of spatial scale. The appropriateness of a design depends on the study system and on the objectives of the study (Williams *et al.* 2002, Pollock 2006), but there are two scale-related issues that appear in any monitoring initiative: detection failure and spatial variation (Yoccoz *et al.* 2001). Detection failure creates the danger of reporting false absences, whereas spatial variation limits the ability to extrapolate results from a set of sampling sites to a larger area of interest. Detection problems require sampling the same sites repeatedly in time (*e.g.*, Pollock's robust design), while spatial variation requires sampling different sites in space (Williams *et al.* 2002).

To monitor a local-scale phenomenon, sampling sites must represent the local spatial variation, and repeated visits in time require travel over relatively short distances. To monitor on a larger scale, the representation of spatial variation will use a coarser grain, sampling sites that are further apart; repeated visits will require more traveling. Either scale can be addressed with approximately the same number of points *if* one chooses one scale *or* the other. The logistics become quickly impracticable, however, if one attempts to work at both scales simultaneously. Such a goal requires both a coarse grain and a fine grain representation of spatial variation over the entire study area, as well as both short-distance and long-distance travel to a much larger number of points. Multi-scale designs are possible in principle, but exceedingly difficult in practice. For example, while we can extract relevant information from a mark–recapture study of a population of primates in one forest reserve, we would never be able to extend the same methodology to a basin-wide study of the species. Conversely, a basin-wide survey of one species' occurrence in large spatial units may provide valuable knowledge about distribution, but a one-time assessment of occurrence in one large area will be of limited use. The efficiency of the design depends on the scale for which it is intended.

Amazon monitoring programs have yet to achieve the desirable focus on scale. However, a number of recent initiatives are potentially suited for different scales. Take the following three examples: Conservation International's *Tropical Ecology Assessment and Monitoring Initiative* (TEAM), planning to establish more than ten sites in three continents, could focus on the global scale (TEAM 2006); the Brazilian government's *Research Program in Biodiversity* (PPBio), aiming to set up at least 12 stations of 25 km^2 in the Amazon region, could focus on the basin level (PPBio 2006); finally, the *Amazonas* State's ProBUC has been set up at the local scale to monitor protected areas (Marinelli 2007). Within the framework of these programs there is good potential for doing more focused work, but in reality, they still try to bridge as many scales as possible—an approach that compromises efficiency.

We propose that every new program should focus on a priority scale. Scale-related aspects of existing designs should be fine-tuned in a spirit of cooperation and complementarity. Initiatives with abundant resources may be able to work at more than one scale, but one can also address multiple scales with integrated analyses of data collected through different programs (Julliard 2004). Integration, however, requires communication; representatives of monitoring programs should meet in a regular forum to review findings, aims, and methodologies. Apart from the three programs cited above, a number of other successful studies could provide useful contributions (Petrere Jr. 1978, Castello 2004). We cannot cite all such studies, but one valuable outcome of a forum could be a publicly available, internet-based information system to assess the scope and limits of existing monitoring programs. Similar systems exist elsewhere in the world. For example, the EU's EuMon database (Henle 2007), presently reviews 541 programs, emphasizing integration and methodological review.

TOO MANY SPECIES?

After defining a target threat and monitoring design, there is the often-monumental task of collecting data. The biological richness of the Amazon is so high that sampling requires skilled specialists that are few and hard to train. Compare the numbers: a classic field guide to North American trees includes less than 800 species (Brockman & Merrilees 2001); 66 1-ha plots in the Biological Dynamics of Forest Fragments Project, central Amazon, contain more than 1200 tree species (Laurance 2001). Not only are there many species, but they are also poorly known (due to incomplete taxonomic knowledge) and hard to find (due to low abundances in a densely forested environment). High richness demands observer quality, but there is a problem of quantity too. The Breeding Bird Survey of North America, for example, deploys thousands of skilled volunteer birders every year (Sauer *et al.* 2006); in the Amazon, there are dozens of birders at most. The Amazon is vast *and* empty, concealing a chronic shortage of labor that has spelled disaster for many great projects (Hecht & Cockburn 1989). It is not enough to have an efficient design for the right threat. To succeed, we need more, well-trained observers.

We propose a two-part solution: first, broaden the scope of potential observers to include the rural population of the Amazon; second, train observers more efficiently. People with detailed taxonomic knowledge of Amazonian organisms are usually academics who gained their practice through years of persistent fieldwork in poorly known regions. These researchers are completing the groundwork that connects natural history, taxonomy, and species identification. As their work advances, there is less need for observers to be academic experts and it becomes increasingly viable to train and employ people from any background in monitoring activities. Instead of sending every observer out to the field, we can increase efficiency by providing technical training and jobs for individuals that reside in the monitoring areas and already have knowledge of the sites and species (Noss *et al.* 2003, Castello 2004).

Memory is the limit for recognizing large numbers of species. It is easier to memorize species that one encounters many times, but there is more to it than just the number of encounters: The temporal pattern of repeated exposure to information has a strong effect on memory, with some patterns leading to better performance than others (Bahrick 1979). Knowing this, experimental psychologists developed algorithms that optimize learning based on spaced repetition of information and implemented them in commercially available software (*e.g.*, SuperMemo). Such systems prompt the user to answer questions and subsequently adjust the temporal pattern of questioning to user performance (Wozniak & Gorzelanczyk 1994, Wozniak 2006). The user-defined questions are akin to electronic flash cards that may include text, images, and sounds. Recognizing that the optimal patterns of exposure to information are not necessarily the ones we encounter in the field, we propose a shift from an entirely field-based training to a learning-optimization approach where computer-based tools complement the field experience. The emphasis on learning optimization might sound accessory in a temperate zone context, but it is crucial in mega diverse tropical regions.

CONCLUSION: THE EYES OF MANAGEMENT

We propose three new directions for reinforcing current progress and satisfying future needs of Amazon monitoring programs: (1) Ensure that every new program is targeted to a well-defined threat; (2) Choose one scale before designing each program, and establish reliable channels of communication between programs, guaranteeing complementarity and methodological standards; and finally (3) Train academic and nonacademic observers efficiently, complementing field training with learning tools that aid memorization of species traits.

Monitoring programs are the eyes of management. The urgency and variety of threats to the Amazon require pause to define which should get most attention. Monitoring is not an end; it is a means to support informed decisions. The design of new programs and the analysis of data from existing ones should follow the manager's choice of priority threats.

Cooperation between statisticians and field biologists has generated a wealth of sampling-design solutions to monitoring problems, in particular, to problems of detection error. To ignore them is to ignore the reality of field sampling. These solutions are purpose-built, meant to address particular challenges at given spatial scales. With a study area of more than seven million square kilometers, Amazon researchers can design efficient surveys for many different scales but certainly not for all of them simultaneously. We must define the intended scale of analysis clearly, based on management needs, and then devise a sampling design that fits that scale. There is no such thing as an all-encompassing solution—only the right design for a pre-defined purpose.

The scarcity of qualified observers is perhaps the most limiting constraint to monitoring in the Amazon. The high species richness in a sparsely populated region requires placing many well-trained observers in far-off places. We must apply creative solutions for training more people in less time—and for having observers where they need to be.

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