The Essential Components for a Sampling System to Monitor Biodiversity

Aware of the uneven geographical coverage of biodiversity research in the country, especially in regions of rapid agricultural expansion, the Brazilian Ministry of Science, Technology and Innovation (MCTI) included "Inventories" in the PPBio program. The PPBio sampling strategy follows the spatial design developed with the PELD (Pesquisas Ecológicas de Longa Duração or ''Long-Term Ecological Research'') plot series. The strategy was based on the idea, that to be effective and efficient, the design of surveys should have the following characteristics:

(1) **be standardized**.

(2) **Allow integrated research with all biological taxa**.

(3) **Be large enough** to monitor all elements of biodiversity and ecosystem processes.

(4) **Be modular**, and so permit comparisons with less intensive sampling done at very large areas.

(5) **Be compatible** with similar already-established research initiatives.

(6) **Be implementable** with existing manpower.

(7) **Provide data quickly and in a usable manner** that meets the demands of the professionals involved with biodiversity and natural resource management, as well as other stakeholders

Combined, these features allowed the establishment of new PELD sites as well as for rapid assessments (the Rapid Assessment Program, RAP) designed for areas of biological interest for their biodiversity or the urgency of an immediate threat. A preliminary description of the combined methodology (called RAPELD) is given in Magnusson et al. (2005).

Standardizing the Scale of Surveys

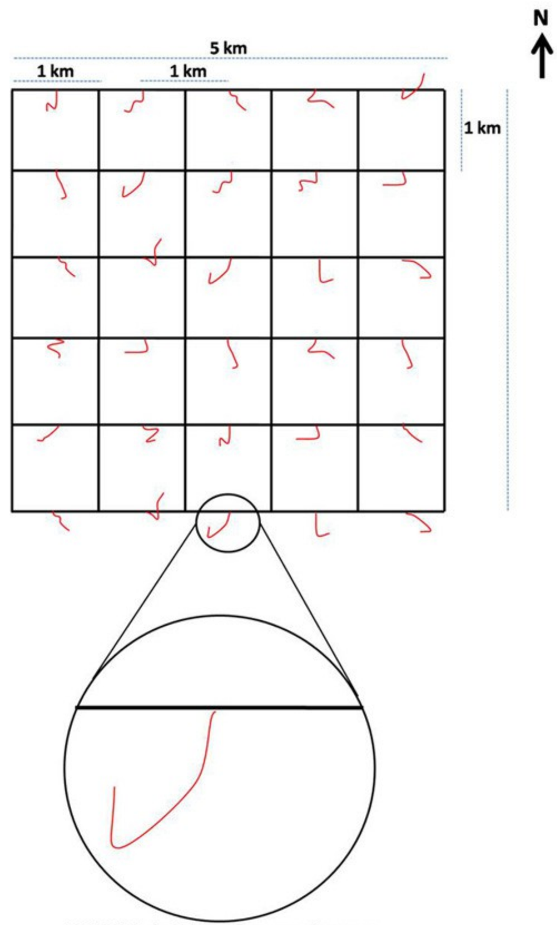
Most researchers use laboratory or collection techniques that are standardized and there is always much debate about which standards to adopt. However, new and better techniques are continually found. It is practically impossible, and indeed not very useful, to try and restrict regarding what kind of reagents or traps a researcher might use, or any other means of studying their organisms of interest.

In reality, this is not as big a problem as it at first appears, and it is often possible to calibrate new methods so that they can be compared with data collected previously with other methods. However, data collected at different geographical scales usually cannot be compared easily (Urban 2005). Biodiversity measures such as species richness and community composition, the extent of genetic variability within a species, and changes in such aspects as biomass and productivity, all are strongly dependent on scale. This is the reason why practically impossible to use many of the extensive databases that have been developed over the past four decades to support the management or understanding of what determines the distribution of biodiversity. Using savanna-based data from studies funded by the PPG7 (Cintra 2004), and studies in tropical forests funded by CNPq (National Council for Scientific and Technological Development), researchers at the PELD site 1 plot series and those participating in the early stages of PPBio's development thoroughly discussed possible sampling methodologies. The result, the sampling system at Reserva Florestal Adolpho Ducke (Ducke Reserve) initially covered 64 km^2 and served as a means of field-testing the methodology. However, an area this size is simply too big to be put in place at a large number of sites. Studies by Carlos Peres at the University of Anglia (UK) and colleagues showed that straight 5 km transects are sufficient for surveys of most large mammals, and that a sampling system covering 25 km^2 (5 km x 5 km) can be implemented at moderate cost.

Using a system of this size, permanent terrestrial study plots are separated by a minimum distance of 1 km, providing a reasonable number of replicas (30-60) for studies on the same site. In addition, in Central Amazonian tropical forests topographic variables are generally not spatially auto-correlated for plots separated by such distances (Kinupp 20055 & Magnusson; Magnusson et al. 2005).

The length of each plot was set at 250 m, because such a length would include a sufficient number of larger organisms, such as trees, to allow analysis of communities. This plot length was independently selected by Alwyn Gentry in his studies in forests around the world and has proved to be valuable and viable in many analyzes (Phillips & Miller 2002). One important difference is that, while Gentry's plots were straight, PPBio plots are often curved since they follow the regional contour in order to minimize edaphic variation within plots. Magnusson et al. (2005) explain the reasoning behind this.

The 25 km^2 grid at Ducke (Figure 1) is appropriate for studies of populations of most organisms. Such a grid is suitable for hydrological and hydro-chemical studies in watersheds, as well as for studies of erosion, distribution of introduced organisms, biomass change and other processes that occur at the landscape scale and which are important for professionals involved with such aspects of land-use as management of and forests, parks and reserves. It was therefore adopted as the basic unit for PELD sites. Smaller modules are used for rapid assessments, but they need to keep the same spatial arrangements as the larger grids in order to maintain comparability with PELD sites and other surveys. Such a design is consistent with the hierarchical approach recommended by Lawson et al. (2005).



Plot of 250m in length following the level curve

Figure 1 - 25 Km2 Grid used for population studies in large sampling sites.

Integrated surveys

Access infrastructure (trails, plots) and accommodation for researchers are among the most expensive items for any lifting system. Independent studies by qualified researchers in each taxon results in an unnecessary duplication (Lawson et al. 2007). This results in total cost orders of magnitude higher than can be achieved by integrated surveys the same rate. Lack of planning is also a problem for professionals involved in the management of parks and reserves because they cannot control or monitor the impacts of researchers if they do not know in advance where the collection effort is applied. In addition to saving financial resources, a permanent integrated system for most surveys allows these professionals to control access and monitor potentially sensitive areas.

Data for different groups of organisms and environmental data cannot be integrated if collected at different scales (more information on standardization). Integrated surveys also allow efficient analysis of data collected on the same scale. The following table contains typical data collection surveys conducted in uncoordinated:

plot	Specie density	Vegetation structure	soil	Altitude
A	4.3	55		
B	5.9			
C	6.7		78	
D	3.8	34		36
E	6.4			

One researcher collected density data on a particular species from all plots that were of interest to his or her particular study. Other researchers collected data from the same sites for vegetation structure, soil particle size and altitude, but sampling was carried out on the same plots only in some cases. Integrated analyzes are not possible because the computer normally eliminates plots that do not contain data for all variables. You can request that the statistical package or Geographic Information System (GIS) "invents" data by extrapolation / interpolation based on other locations, but few researchers do this because of the questionable validity of the subsequent analyzes. Anyway, the degrees of freedom for statistical analysis should not be higher than the actual number of investigated sites.

The following table contains structured data that enables a wide variety of analyzes to be carried out and the data can be reused for a wide variety of purposes:

plot	Specie density	Vegetation structure	soil	Altitude
A	4.3	55	28	23
B	5.9	87	44	113
C	6.7	65	78	57
D	3.8	34	59	36
E	6.4	66	41	98

This type of data can be collected at much lower cost, and is more useful. Therefore, PPBio surveys are based on standard modules, each of which may be used for a wide variety of organisms.

Big size

Gentry plots were used to describe the variation of diversity within and among geographic area units. However, there is high small scale Beta diversity (1 - 10 km) in the vegetation of tropical forests, even within the same "type" of vegetation, such as upland forest (Clark et al. 1999[15], Phillips et al. 2003[16], Tuomisto & Ruokolainen 1994[17], Vormisto et al. 2000[18], Tuomisto et al. 2003[19]). Therefore, the sampling area for comparisons within the same site need to be large. Small plots (1-100 ha) capture a very small part of the diversity of a site for most taxonomic groups. This is the main reason that many plots of 0.1 ha are far more efficient than 1 ha plots with the same total area (Phillips et al. 2003[16]). For comparisons between sites, we consider that the grid system is a single plot composed of many sub-plots. For analysis within the same site, each installment or sampling module adopted should be considered an independent replica.

The basic unit for LTER surveys proposed within the PPBio is a system of trails in the form of a 5 km x 5 km grid on which permanent plots are systematically distributed. LTER sites are used to monitor changes in environmental and biological variables, and the site as a whole needs to be large enough to monitor phenomena that are of interest to users and professionals involved in forest management, reserve management and planning land use. Smaller plots (1-100 ha) can be useful for specific issues, and even smaller plots can reveal undescribed species, but are of little use for recording the diversity of large and mobile organisms, many of which are of economic or conservation interest . Ecosystem processes such as biomass accumulation, erosion, pollution and sedimentation work in large areas, and can only be assessed in large areas. For example, within most forest stands, you can find patches of 1 ha virtually intact, 1 ha patches that have been cut and large areas with roads and compacted trails. However, no one needs to point out these effects to professionals in forest management, they are obvious. These professionals are interested in large-scale phenomena that may affect biodiversity or economic returns in the future. Only sampling systems covering dozens of square kilometers can provide the necessary information for the management of land use.

Alpha Diversity (small plots) in tropical areas may not be much higher than in temperate areas, but changes between species ratios (Beta diversity) can lead to a much higher range diversity (Mendonça et al. 2005[20]). Furthermore, for a given plot size, Alpha diversity indices are normally inversely related to the average size of organisms being studied (Magurran 2004[21]). For this reason, Alpha Diversity estimates usually are of little use to applied or theoretical research (O'Hara 2005[22]). The distribution of plots over 25 km2 allows evaluation of Alpha and Beta diversity at a landscape scale potentially useful for the planning of land use, and allows for the evaluation of most, if not all, of the components of biodiversity.

Small plots (1-100 ha) capture a very small sample of the topographic and edaphic variation in most areas (see figure Compatibility with Existing Initiatives), and most organisms specialize in a certain range of topographic or edaphic gradients.

Small grids provide very little information about organisms closely linked to drainage characteristics, which are often the first to suffer the impact of human activities. A large size is also important because space can be replaced by time-integrated type relationships time-area (Adler et al. 2005[23]). It is easier to obtain short-term aid for projects that show quick results than to get long-term aid for products that take a long time to for results to appear. PPBio grids are the only widely used surveying system that includes all sizes of terrestrial and aquatic environments (not seasonally flooded) at a reasonable cost and in a timely manner.

PPBio Grids and Modules

On the scale of the Amazon basin (or of the country or state), each grid is a sampling unit, and the units of sampling are smaller sub-units. For long-term ecological studies within the same site, there are spatially explicit standardized modules that allow comparisons within and between grids. Not all organisms can be efficiently sampled in the same sampling unit. However, the greater the number of taxa sampled within the same sample unit, the more comparisons can be made, and the greater the chance of finding biodiversity substitutes (surrogates) with a viable cost-benefit ratio. In addition, many of the groups with economic potential for the pharmaceutical industry (including fungi, bacteria, viruses, and insects that concentrate plant secondary compounds) are often closely associated with higher organisms, such as woody plants or vertebrates. Only integrated studies can reveal their interactions and allow the assessment of the economic value for industrial use.

Predictive variables, such as soil characteristics, water chemistry and vegetation structure, may be recorded as standardized modules, making it unnecessary for every researcher invest time and money to obtain the same data. Since collecting predictive data variables (e.g. chemical analysis of soil) is often more costly than collecting specimens, reducing such duplication of effort can lead to financial savings orders of magnitude greater than the simple amount of time that is saved. Reducing duplication of effort can also be important for professionals involved in the management of parks and reserves. Although methods for collecting environmental data (e.g. soil samples, leaf-litter collection, measures of all plants in a given small area) typically provides only a small impact, multiply that impact by the number of researchers using the site, and the potential impact could be great indeed. Consequently, avoiding data collection duplication also benefits the management of parks and reserves.

For these reasons, researchers defined a series of standard modules that can be used for specific groups of organisms. Other modules may be included in the future as the demand arises, but to-date all organisms investigated within the PPBio grids could be efficiently studied using one of the following modules:

1 **Terrestrial Plots**: plots systematically distributed along the grid, appropriate for estimates of biomass (woody flora to microbes), the majority of terrestrial invertebrates, small vertebrates and most of the flora.

2 **Aquatic Plots**: plots in watercourses - suitable for studies of fish, crustaceans, aquatic insects and aquatic vegetation.

3 **Riparian Plots**: plots along the edge of waterways, suitable for riparian and aquatic species that are closely associated with water courses (e.g. frogs, snakes, fish and tadpoles in puddles).

4 **Trails**: suitable for medium and large vertebrates and rare plants. May also be useful for studies of genetic variation within a grid.

These modules have proven effective for habitats as diverse as Pantanal floodplains, and savannas and tropical forests in Amazonia. Given the success of its application in these environments, it is likely that these modules will be effective in most terrestrial or semi terrestrial ecosystems. The sampling scheme has not yet been tested on lowland floodplains, coastal and marine areas. However, the sample design with trails and permanent plots of a constant altitude (i.e. depth) could be adapted to sample the great biodiversity in aquatic ecosystems (including marine ecosystems). Only the mode of transport and sampling instruments would need to be modified.

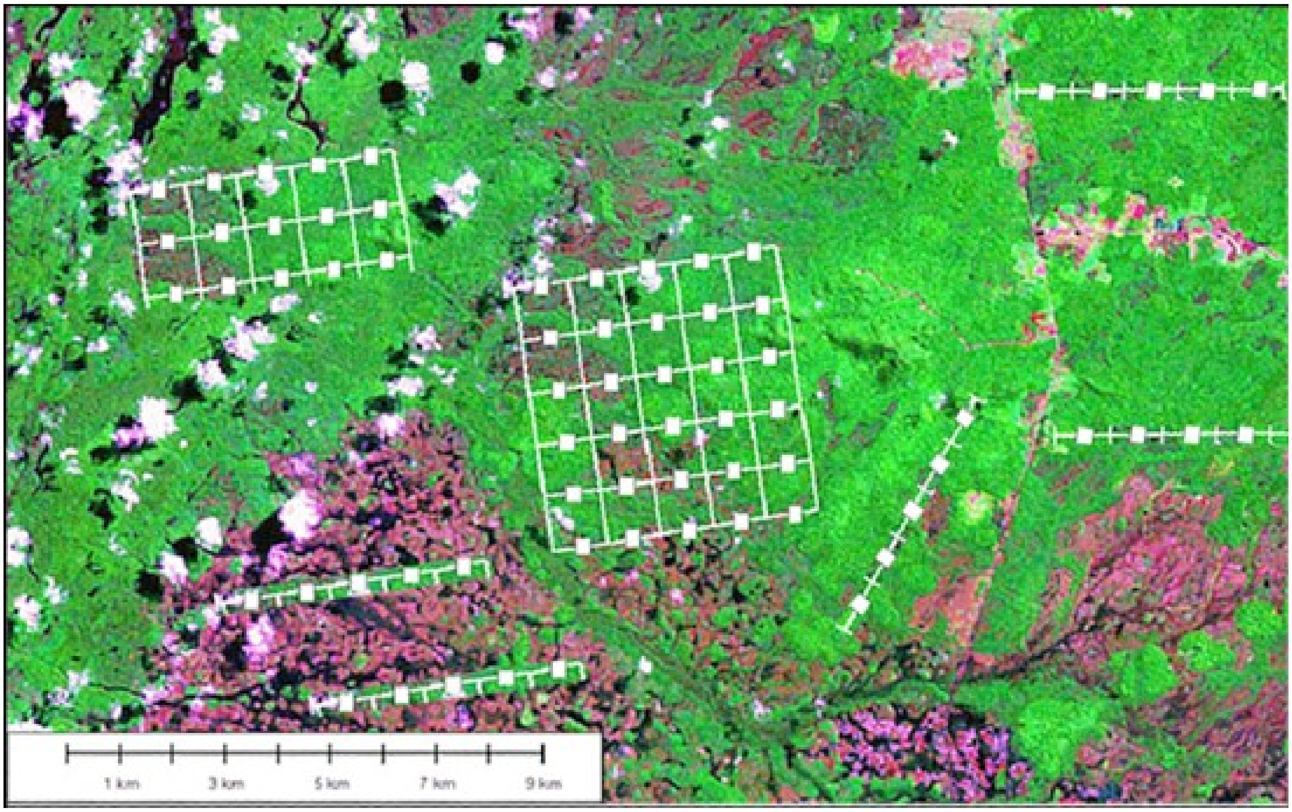
The PPBio plots' modular nature is important because it is not feasible to install large grids in remote areas lacking infrastructure or where development is likely to completely eliminate the majority of biodiversity very soon or very quickly. Therefore, for rapid assessments (RAP), it is necessary to have standardized modules that can be put in place both speedily and cheaply. Comparisons become more difficult when the grid design differs from the full PELD/LTER surveying grid. In addition, it is often difficult to attract researchers to conduct monitoring projects on grids that do not replicate the PELD/LTER model, especially for studies for masters dissertations and doctoral theses where comparability is essential. However, with appropriate statistical adjustments, much useful work can still be conducted under such circumstances.

Grids not covering the standard 5 km x 5 km were used to assess biodiversity distribution of in areas where replication is more important than precision, and existing trails allowed the installation of PPBio systems at low cost (e.g. within the existing permanent plots at the Forest Fragments study - PDBFF). In another example, pairs of 5 km trails (1 km distant from each other) were used when sampling biodiversity to assess the potential impacts of the BR 319 highway between Manaus and Porto Velho (see figure at bottom of page). While riparian plots somewhat smaller (200 m) than the 250 m normally used in PPBio work were deployed when assessing the distribution of amphibians in natural habitat remnants within the city of Brisbane, Australia. Aquatic plots have been used to conduct fish surveys in areas potentially impacted by gas and oil exploitation in the Amazon. The figure illustrates how modules could be used around the primary grid in Viruá National Park for surveys in remote area, with additional grids placed in areas around the park identified by remote sensing as having very different habitats, and so assess human impacts on areas around the park (this figure is, in fact, hypothetical, because at the moment only the primary grid has been installed). The training of researchers and students in PELD/LTER sites should provide local potential to conduct RAP surveys in the near future.

Efficiency in large projects

To achieve a more efficient outcome when monitoring the environmental impacts of large projects (logging, hydroelectric dams and others), and to ensure that such monitoring is conducted across the widest possible variety of biodiversity components and ecosystem processes, we recommend the following module:

Two parallel trails 5 Km in length and 1 Km apart from each other, with uniformly distributed plots and a variable number of aquatic and riparian plots, as shown in the figure below:



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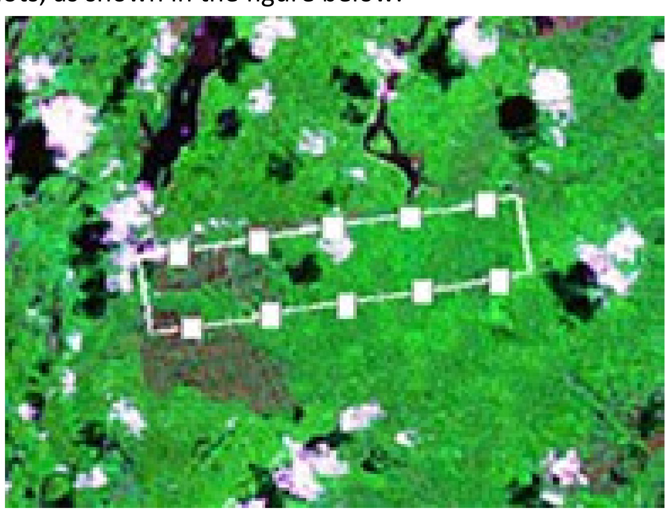
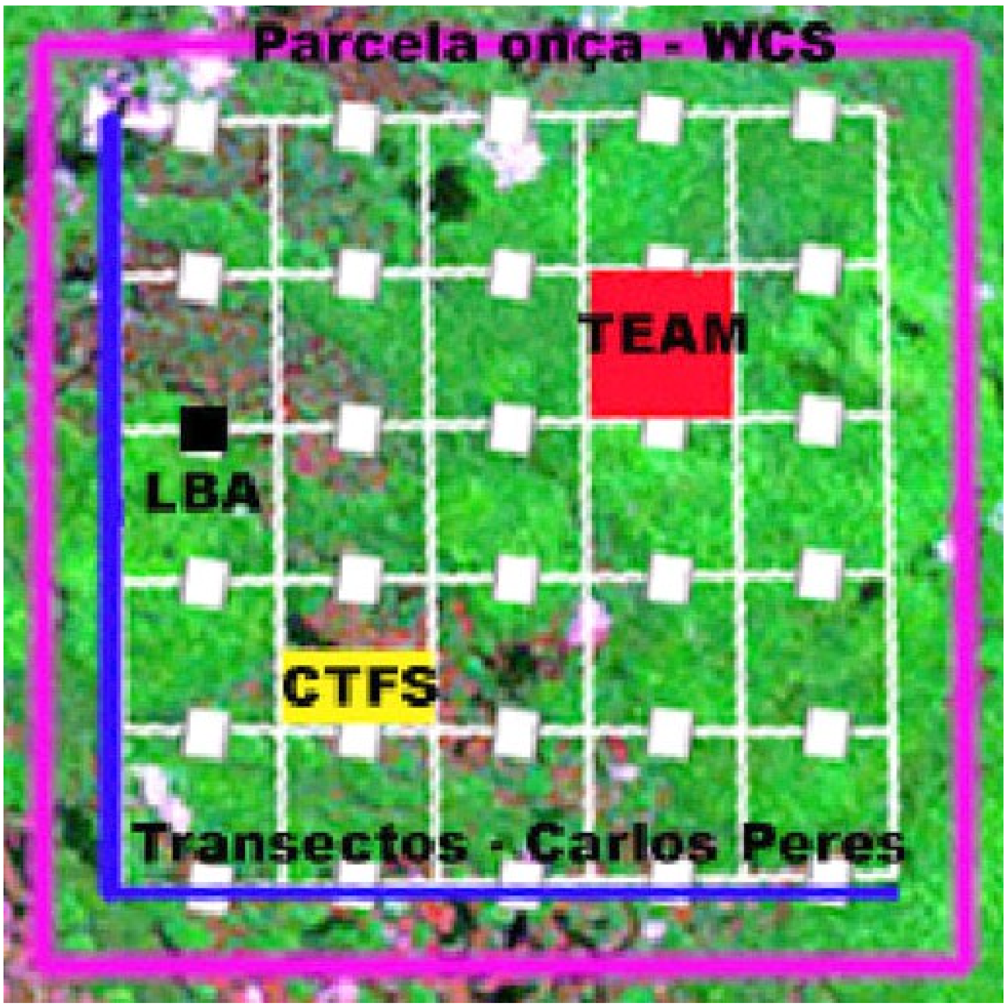


Compatibility with Existing Initiatives

Several initiatives for biodiversity monitoring are taking place. For the reasons already discussed, these initiatives have taxonomic and geographic coverage limitations. However, they have accumulated extremely valuable data that can be used to assess the long-term trends for some groups. To maximize the usefulness of PPBio LTER sites, and modules used for bioprospecting and impact assessment, it is important that data from these initiatives can be integrated with data collected by PPBio. That was one of the main considerations in the design of the first PPBio trails and modules.

The following figure shows a PPBio hypothetical grid with modules used by some of the biodiversity or ecosystem monitoring projects.



The central plot of 100 ha used by TEAM Conservation International fits in one of the squares of 1 km x 1 km delimited by PPBio grid system (see red square in the picture). There are two TEAM plots in the Ducke Reserve. The vegetation survey is done in smaller plots within in the 100 ha plots and large woody plants are surveyed only in a central plot of 1 ha. TEAM sites are too small for the effective monitoring of most mammals. Therefore, camera traps and other surveys are conducted outside the main grid, which undergoes intense disturbance by human presence. PPBio trails provide access to adjacent areas, and TEAM camera traps are used throughout the Ducke Reserve, using the PPBio tracks for access.

The Smithsonian Institution, the CTFS initiative, installed expensive 50 ha plots around the world which are being used to revolutionize thinking about the dynamics of tropical forests. A standard plot of 50 ha of CTFS would cover half of the squares of 1 km x 1 km bounded by PPBio grid system (see the yellow square in the figure). The CTFS plan to install a site within the grid in the Ducke Reserve, but is awaiting of resources to be made available (Kyle Harms, personal communication).

The Large Scale Biosphere-Atmosphere (LBA) experiment in Amazonia was originally a joint project between the US space agency NASA/USA, the European Union and the Ministry of Science and Brazilian Technology (MCT), which is currently being continued as a uniquely Brazilian project. It is an example of high-tech being used to study ecosystem processes that is most effective when incorporated into a mesoscale program like PPBio so that the high cost data produced can be widely used. (See the black square in the figure). A coordinated effort between the LBA and PPBio plans to install PPBio grids around each LBA flux tower.

Standard plots of 1 ha for vegetation survey are used in conventional studies of botany and forest sciences and can also be easily accommodated within the PPBio plots. The grid Ducke Reserve is already part of the Amazon Tree Diversity Network. In the PPBio grid on Maraca Island (RR) many permanent plots for vegetation studies have been installed by Jose Fragoso and employees. Heraldo Vasconcelos used the same modules to sample ants in areas where the vegetation had been removed in conventional plots of 1 ha in the PDBFF.

Carlos Peres of the University of Anglia (UK) and his colleagues have conducted extensive surveys of medium and large mammals throughout the Amazon. Many of these surveys were based on standardized transects of 5 km. The PPBio grid was designed to allow mammalian surveys comparable with those already conducted by Perez and co-workers (see the blue lines in the figure).

The Wildlife Conservation Society (WCS) conducts intensive studies with jaguars (Panthera onca), a top predator in most terrestrial ecosystems of South America. A 36 km2 grid is considered optimal for jaguar studies (Andrew Taber, personal communication) . Despite being much larger than a standard PPBio grid, this area can be obtained by simply adding extra tracks to cover a range of 1 km around the basic grid (see the magenta line in the figure). Another top predator, the Harpy Eagle (Harpy harpyja) was detected and studied in Reserva Ducke using the grid system (Tania Sanaiotti, personal communication).

Field work for implementing surveys

Many of the proposed long-term biodiversity monitoring projects foundered due to lack of financial resources to employ the large number of skilled personnel required for the technical monitoring, as well as the high costs for installing some of the proposed systems. For example, the Smithsonian Institution has a global network of forest research plots and scientists studying tropical and temperate forest. Called CTFS (Center for Tropical Forest Science), it has over fifty forest research plots across the Americas, Africa, Asia, and Europe, where the survival and growth of some 4.5 million trees from 8,500 species are monitored. However, installing and inventorying the vascular plants in each 50 ha plot costs over US$300,000, with maintenance costs on-going. Few organizations have the ability to install and maintain large networks of plots at prices like this.

Key stakeholders in the long term monitoring of PPBio PELD sites include organizations responsible for reserves and wildlife (e.g. National Parks and other protected areas) and land use planning (e.g. municipalities and federal environmental agencies), plus universities needing sites to train students, private land owners with economic or conservation goals, and many others involved in land use. Interested parties must provide the infrastructure to maintain the site. The costs are very moderate. Very often, grids can be installed by engineering students or students conducting surveys. Even if a contractor is hired to install the grid, the cost is less than $50,000. In Brazil, this provides the infrastructure to do surveys of a wide variety of flora and fauna groups on a scale that is relevant to management. The involvement of these people is important. They not only protect the grid, they also ensure that researchers conduct research on a relevant scale for management using consistent survey methodologies.

The first PELD trails in Amazonia were funded by the Ministry of Science and Technology (MCT), either directly or via CNPq (National Council for Scientific and Technological Development). Almost all RAP surveys using the methodology PPBio were funded by special interest groups. RAP modules can be installed at a fraction of the cost of the total grid, usually less than $ 1,000 per module.

Academics from universities and research professionals need to be involved in the surveys to ensure scientific rigor and maintain data quality. However, such professionals are few and usually overworked. Despite their undoubted competence, and the benefits of reproducibility, it is simply impractical to try to ask such individuals to conduct all the desired biodiversity surveys. Therefore, much of the survey work is done by university students.

University students, especially those working towards masters dissertations or doctoral theses, are among the most productive scientists. More importantly, they are still young and have the desire to work in remote areas under difficult conditions, and typically receive grants or other funding, and such circumstances are generally exempt from many of the costly legal liabilities associated with labor laws. Students using the PPBio system have, besides the infrastructure, access to a database with most of the environmental data (s)he will need for answering interesting scientific questions about a particular taxon, and access to data about other taxa collected by other researchers. A student can participate in integrated studies, while focusing on the biology of their chosen group, knowing that data will be available about the grid. Due to the availability of high quality environmental data and integrated studies, what was only a glorified lists of species becomes data that can be published in a high quality scientific journals. In this context, it is interesting to note that the first PPBio grid in the Pantanal was funded by the Ministry of Education (MEC/CAPES - Coordination of Improvement of Higher Education Personnel) with aid given precisely to increase the quantity of publications of professors and students in a local Federal University.

The interaction between students and managers is one of the most important aspects of PPBio sites, since it is so important to train the next generation of professionals in land use. The Ducke Reserve is almost 3 times the size of the standard PPBio grid. Since it was installed in 2000 this grid has been researched for above-ground tree biomass (twice), stream fish (twice), lake/pond fish, lizards, frogs, tadpoles, woody plants, herbaceous vegetation and many entomological groups. All surveys were conducted by students as part of their theses and dissertations, and the great majority have had their results published or accepted for publication in high level scientific journals.

Managers often ask about the frequency with which the surveys should be conducted. In some cases it may be necessary to adjust survey frequency to accommodate the biology of a particular group. However, for most groups, researchers are evaluating the probability and types of change over time. Some aspects - such as soil, may change very slowly, and will be of scientific (and management) interest only for surveys made at decade-long intervals. In contrast, groups such as butterflies can respond to an annual variation in climate, while other groups such as ants or primates, may show intermediate responses. There is no reason why survey data should not be shared. Recording changes benefits both scientists and management. Researchers (and their students) are always looking for publishable results. Database information regarding biological and environmental variables also enables the formulation and testing of hypotheses about connections and subtle ecological interactions. The PELD monitoring structure becomes a highly lucrative scientific activity, even when there is no immediate financial return. Bioprospecting and other economic activities generate their own funding.

There is enough funding available to work with biodiversity in remote and interesting areas like the Amazon. However, the ability to achieve all that could be done is hampered by the lack of skilled manpower. All too often, regional areas have university scientists, but many of them have become involved in a vicious circle of low productivity, making them uncompetitive for obtaining grants, which means that they cannot improve their productivity. Funding agencies are understandably hesitant to provide funding for studies with experimental designs of low quality, and for researchers that are unproductive and with few scientific contacts. The goal of PPBio, especially with PELD sites, is to break this self-perpetuating cycle of under productivity. The PELD sites bring a robust experimental design in which even basic inventories can be used to answer important questions about biodiversity and ecosystem processes. The PPBio Program provides training for local students and researchers and, more importantly, provides a conduit for scientific exchanges between regional consortia and institutions established in other regions. Such flow is central to maintaining the quality of research. Therefore, PPBio provides a general framework for exchange between local, national and international researchers which can work to the benefit of all.

Data Availability

PPBio works on the principle that data collected on public land, or by public officials, or by using the infrastructure provided by public funding, are public property and should be available for all professionals who wish to use it. The availability of PPBio data is governed by an explicit Document Data Policy. In essence, this states that data must be entered in the database within months of collection, but will not made public until after a two-year period without the permission of the person responsible for the collection of that data. After that, with few exceptions, the data becomes public and freely accessible on the Internet. Restrictions on the availability of data after two years are made only if such publication could infringe the rights of third parties (e.g. traditional knowledge), or result in the exposure of species to danger (e.g. records of threatened species or those of economic value).

Several databases of biological and ecological are available, but most are of little use to anyone beyond the original collectors of the data. One of the main reasons for this is that it is not possible to build databases from which it is efficient to extract information when the general issues that motivated the data collection are not known beforehand. In contrast, PPBio databases are specifically designed for use by people interested in the distribution of biodiversity and the factors affecting it. The basic data fields that allow queries are associated with geographic coordinates and dates. Data in the main files are always accompanied by detailed information about the collection effort. It is this information that allows the estimation of false absences, and the estimated economic value (density) of resources.

Metadata describes the data and how they were collected. Metadata should be released immediately, sometimes even before the collection so that other researchers and managers know what is being collected and where. Metadata is essential to make the data usable by other researchers. The protocol adopted by PPBio metadata follows the EML standard. Data storage without adequate metadata is not permitted on the PPBio database system.

Data are always geographically explicit. PPBio data is available in four types:

(1) **Data on organisms or environmental data from sites using the PPBio LTER sampling pattern**. Data of this type are the most complete and the most useful for long-term monitoring and geographical comparisons. Standard environmental data are provided for plots within the PPBio grids. These are probably adequate for most analyzes. As reserve managers or researchers may have more detailed information about a particular grid, we recommend that interested researchers check data availability for specific grids when planning their studies. Studies conducting monitoring within grids must use methods described in metadata data from previous PPBio studies, or include a calibration phase within the project to ensure that data are comparable. Researchers should provide data for all PPBio modules of a given type within a grid, and must agree to follow the PPBio Data Policy.

(2) **RAP data for a specific geographic area, collected using sample plots, but not the complete PPBio LTER grid pattern system**. This type of data is most useful for environmental impact studies and for extrapolation to larger areas. If these data are to be used for long term monitoring, researchers and managers must look for long-term financing, because such work is not as attractive to students and other researchers as repeat surveys. Researchers must agree to follow the policy data PPBio.

(3) **Ecological data collected pre-PPBio and using different methodologies from the PPBio standard**. This data type is only available on the PPBio database if the authors provide detailed spatial and temporal metadata that potentially allow calibration of their data with the methodology currently used by PPBio (i.e., the collection effort should be stated explicitly and be repeatable). Researchers must agree to follow the PPBio data policy.

(4) **Ad hoc data on organism distribution.** This is the data group of with the lowest quality (the third tier of Lawson et al. 2005). This kind of data is of little use except to describe the known distribution of organisms, but may be the only type of data available for high mobility species such as Harpy eagles. The minimum requirements for this data type are the date and geographical coordinates. The collection effort will be unavailable. This information is provided primarily for some PPBio participants (e.g. IBAMA – the Brazilian Environmental Agency) to have easy access to data. Other databases (e.g. BIOTA-FAPESP) have already made such data available in a useful form for localities records based on specimens deposited in collections. Despite this not being a major focus of the PPBio inventories component,it is a major focus of the PPBio Biological Collections component, and stakeholders who have collected specimens should contact appropriate PPBio Collections Component coordinators.

The identification and the safe storage of specimens in museums are essential if biological surveys are to be effective. This is the responsibility of the PPBio Biological Collections component. When and where material deposited in museums was originally collected can be very useful. Consequently, all identified field collected material used in PPBio Inventories must be accompanied by data which allows reference to material deposited in museums. This means collecting information field numbers and museum reference numbers. The PPBio information sector is developing methods of online information integration for field and museum records.

Data availability is very important financially to PPBio. It is the collaboration and the availability of integrated data that makes research in PPBio grids so attractive. Without this, the program would have to directly fund all monitoring using funding from government sources or private organizations, and this is not feasible.

Target Groups for Monitoring Biodiversity

Managers often commission “ biodiversity” research, without understanding that it is unfeasible to obtain data on all aspects of biodiversity in a timely manner with the resources normally available for biological surveys. Recently, MMA, IBAMA, ICMBIO / ARPA, and SFB have had meetings to discuss what groups would be appropriate to monitor for environmental impact studies and in protected areas and forest concessions and these serve as the basis for decisions concerning specific cases. While the following examples refer to monitoring biological groups in forest reserves they illustrate concepts of effectiveness and efficiency for all important biodiversity monitoring work. [Note: A Forest Concession is a where the government gives rights (via a bidding process) to a company to manage a public area and harvest forest products or otherwise use its resources sustainably in accordance to the Forest Management Plan.]

All meetings recommended the use of RAPELD, which is the system adopted by the Research Program on Biodiversity (PPBio). The RAPELD system was designed to allow surveys of any biodiversity component, but the system does not set targets that need to be determined in relation to the needs of each user, and available resources. It is expected that in the long run, surveys of all groups are made in all RAPELD modules, but this is not a feasible objective in the short term. Here, we describe how surveys would be undertaken in standard RAPELD modules (5km x 1km), but the same logic applies to larger or smaller modules.

Vegetation

All meetings recommended vegetation surveys, but surveying everything would be very expensive in terms of time and financial resources. A group that can be sampled rapidly, and that has value to many users, consists of commercially valuable trees with a diameter exceeding 30 cm (DBH). This group may be sampled on module trails with the aid of an expert experienced in timber work, using the transect method (Buckland et al. 1993). The experience of Dr. Ana Albernaz (pers.) of the Museu Paraense Emílio Goeldi indicates that setting up a standard module (5km x 1km) takes 3-4 days and provides useful data for estimating the value of forest timber and complementarity in the composition of the tree canopy. In the first survey on an annual production unit (APU), the trees should have all been identified and the survey for monitoring purposes serves to validate the work of the concessionaire. In subsequent surveys, the trees should be marked to allow for assessment of the dynamics of the species being exploited (Natalino Silva pers.).

Non-timber species groups may be affected by logging, climate change and other human interventions. Unfortunately, surveys of all the non-timber groups are very difficult, mainly because it is difficult to obtain source material for most of the year, and many herbacious species have very limited distribution even when not affected human activities. Pteridophyta is a plant group that is relatively easy to identify all year round and can be sampled in RAPELD plots with great precision. There are relatively complete identification guides, and most species are well distributed throughout the Amazon region, limited only by the ecological conditions on site. Hence they are excellent environmental indicators.

Mammals

Mammals are very popular with the general public, especially large and medium sized species. However, small species present difficulties in capturing and identifying and this limit their use in standard large-scale surveys. The large and medium-sized species, which are hunted, are relatively easily sampled using line transects, i.e. the module trails. Primate surveys, a sensitive group to the changes in forest structure caused by selectively cutting timber are especially easy to sample. Other hunted groups and endangered birds (e.g. Cracidae) can also be sampled using the same survey trails.

Amphibians

Amphibians are considered to be globally threatened and are good indicators of disturbance by humans. Although some amphibians are extremely difficult to detect, especially caecilians frogs are relatively easy to detect. The diurnal species are useful for indicate anthropic changes because they are not restricted to areas with free water (Menin et al 2007). It would be relatively easy and economical to conduct surveys of diurnal frogs in RAPELD plots of uniform distribution. Nocturnal species could also be included, but this would require a higher level of expertise.

Fishes

Aquatic systems are heavily impacted by human activity everywhere, and fish are sensitive indicators of the effects of logging in the Amazon (Dias et al. 2010). Streams integrate environmental impacts throughout the watershed, and should be monitored frequently. Invertebrates can also be sensitive indicators, but the identification of immature stages of Amazonian insects is difficult. In contrast, fish are relatively easy to identify, and identification guides are being developed (Zuanon with. Comm.).

Ecosystem processes

Ecosystem processes were identified as targets in the above meetings, probably because the meetings emphasized biodiversity and the RAPELD system allows some ecosystem processes to be monitored at little extra cost. The physicochemical conditions of watercourses are routinely sampled during surveys of fish populations (Mendonça et al. 2005). The cost of installing piezometers (for monitoring fluctuations in the depth of the water table) in RAPELD plots is low and they can be monitored during surveys of organisms in the plots where they have been installed or by local people.

The cost of monitoring carbon stocks is higher, but since information about carbon stocks can be important for conservation related decisions (but perhaps not for forest concessions), the investment may be worth it. This type of survey requires the measurement and marking of trees in plots distributed across the landscape (10 per module) and the identification of species, usually from infertile or non-reproductive material. The time required for doing this is normally around 4-5 days for each plot. Even without identifying the species (which reduces the accuracy of carbon estimates), the activity requires 4-5 days of work per survey plot on the first pass. Subsequent surveys are much faster because most plants are already marked / identified.

RAPELD FAQ

Why modeling instead of simple sampling?

The sampling intensity depends on the complexity of the variables being sampled, but in general, a random sampling from 2 to 4% of the area is required to have sufficient precision to draw relevant conclusions for the management of land use. In the case of an Amazonian 200,000 ha Conservation Unit this would mean fully sampling 4000-8000 ha, which is not economically viable today. Also, the sampling distribution depends largely on the ease of access, and sampling completely randomly or systematically is generally not logistically feasible. RAPELD uses a system that allows use of predictive models based on environmental variables that can be remotely sensed derivatives (usually topography, soil characteristics, distance above the nearest drainage) in order to extrapolate the results to larger areas and make management decisions.

Why show all appropriate sampling units for a given target in each module?

This is necessary to show to all the variability in a landscape. For example, it has been shown that even estimates of woody biomass which are made in larger plots (up to 1 km x 0.5 km) give biased results because of the biomass asymmetry between species loss (fallen trees) and accumulation (growing trees) (Fisher et al. 2008). The RAPELD system is the only one with enough local repetitions to understand ecosystem processes within a region (Castilho et al. 2010).

Why sample all the targets in the same sample units?

This is necessary to reduce costs and use the data generated by one target group as a predictor for others. For example, in standard uniformly distributed RAPELD plots, soil data and the distance to the water table is used to predict the distribution of woody biomass and vegetation structure. These data, plus the vegetation structure, are used to understand the distribution of organisms, such as scarabs beetles, amphibians, etc. If you need to separate plots and measure these variables independently for each target group, the costs increase exponentially.

Why not use rectangular plots of similar size to the plots which follow the contour?

Rectangular plots of 250 m in length can pass through very different conditions and the use of a data "average" for predicting variability results in very inaccurate forecasts. For example, many studies using RAPELD in the Amazon have pointed out the importance of distance above the water table as a predictor for the biota. This needs to be modeled, because all climate change forecasts result in changes in variability. A change of 30 cm in the water table could have drastic effects on the biota, especially because productivity is limited by super saturation of the soil in many areas of the Amazon (Saleska et al.2007). A straight or rectangular 250m plot could vary by 10 m or more in the distance to the water table. Attempts to predict the effect a change in a 30 cm portion of this would be completely useless. Dividing the plot into subplots to increase the accuracy of predictive variables would not work because the 250 m length was selected to optimize the accuracy of measurements of biota composition, and the cost of measuring these variables (eg with piezometers) in each subplot would be very high. Also, small subplots with high precision for the predictor variables results in data with very little precision for the biotic component.

Another important aspect is the deployment cost. The goal should be to increase the number of sampling modules using resources from other partners, because ARPA can not afford to pay for all costs. rectangular plots must be implemented by a surveyor, because a flat-altimetry survey is required to determine the actual plot size for extrapolation purposes using GIS. In contrast, plots following the contour can be implemented by students, analysts, or local communities with a simple inclinometer and a little training. The involvement of local people may not interest the researcher, but it is a very important element for Conservation Unit manager. Many RAPELD plots are being implemented and have been implemented in the ICMBIO protected areas with the help of fire brigade units, and is due to the training and awareness of the brigade members.

It is easy to implement RAPELD system?

The system is efficient and economical and it is easier to implement than any other monitoring system. In the early stages, it needs people with experience to accompany beginners. Below, we list people who have published on the target groups using the RAPELD method, or defend their graduate thesis on studies using RAPELD or guided those studies. We strongly recommend that these people are consulted before publishing guidelines on the method recommended by PPBio (the RAPELD system).

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