Some Aspects of Inventory Integration

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Abstract.—Integrating such disparate topics as are covered by this conference is daunting, because to do it well requires in-depth expertise of many complex technical methodologies. Based on experiences in Asia and Australia, it is suggested that there can never be one inventory design or one planning system. It will increasingly be necessary to implement specialized inventories and projects that are oriented towards meeting specific short-term and longer term objectives. Each separate study must be designed to enable all the information to be integrated in order to answer the various alternative questions that will emerge in the future. Systematic sampling may often be preferred as the more pragmatic alternative to stratified random or multi stage, multi phase designs. Stratification will increasingly be carried out after plot measurement rather than before. It is often appropriate to build redundancy and flexibility into the project even at a significant cost. No one approach is correct for all circumstances, and any planner or inventory designer must understand all the disparate technologies in order to put together the most appropriate total package of linked systems.

This paper discusses some aspects of a strategy for collecting and integrating natural resource information based on practical experiences in intensive plantation management and extensive natural forest inventory and natural resource survey in various Asian countries and Australia. It is not intended as a single definitive statement but indicates that what is required is a flexible philosophy that can meet objectives as they change and emerge.

EVOLUTION OF INVENTORY DESIGN

Inventory field work is expensive. In the past this high cost has led to the implementation of stratified random sampling designs because these enable just enough samples to be measured in each stratum to achieve the design criterion. Incorporation of remote sensing and other spatial technologies for stratifying the forest led to multistage and multiphase designs that were optimized to achieve specific design criteria at minimum cost. Field work was replaced by calculation complexity. The generally adopted procedure was to design the inventory, then stratify the forest, and then establish the field plots.

Although this is obviously the ideal approach, my experience has been that such designs are not appropriate in developing countries where the objectives of the inventories are often not so clearly defined; even if the objectives are well defined at the time of the inventory design, they have a habit of evolving over time into something quite different. What is needed is a flexible design that can meet changing objectives and changing needs. The design must also be allowed to develop as the skills of those working on the inventory develop and as their knowledge of the resource continually improves. This requirement for flexibility comes at an economic cost. However, without some flexibility, the risk that the inventory will not meet the changing objectives can be great.

In my opinion there are two practical difficulties with stratified random sampling and the more complicated multiphase multistage designs. Forest inventory is generally arranged in a manner that imposes a tight time schedule, and there is commonly not enough time to carry out the stratification before beginning the field work. Generally these two functions must be carried out in parallel even if this does increase the total cost. One example of this was the National Forest Inventory in Indonesia (Leech *et al.* 1996, Rombouts *et al.* 1996), a project that lasted approximately 7 years. The stratified random design proposed in the original documents was necessarily changed to a much higher systematic sample of field plots that could be established while the geographic information system (GIS) was being implemented in parallel. The stratification used for the preparation of the final statistics was available only during the last year of the project. The field work began in 1991, access was difficult in most areas, and species identification was also an almost intractable problem. At the end of the project, some 93 percent of the field plots had been measured, but only 91.5 percent were available for including in the final report. Stratified random sampling would have made it

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impossible to complete the project within any reasonable time frame, but systematic sampling with post sampling stratification was feasible and effective, even though more expensive in terms of field work. It was a pragmatic rather than optimal solution.

The second difficulty that will become increasingly important in the future is that the use of GIS and various remote sensing and other technologies allow new stratifications to be developed almost at will. Certainly given the currently available technologies, any stratification developed before a 5-year program of plot measurement is likely to be largely irrelevant when the time comes to prepare inventory summaries. In the largest mangrove forest in the world, the Sundarbans Reserved Forest in Bangladesh, the systematic sample can now be used to determine which of various stratifications, such as alternative salinity stratifications, provides the most statistically efficient stratification. The plots can now be used to evaluate alternative stratifications that may be quite contradictory. This would not have been as simple if a more economically and statistically efficient stratified random sampling design had been implemented. What seems to me to be the best balance is to use a systematic grid and then to select points within that grid at random. Plot locations are then recorded by their nominal spatial location, but the actual location is also recorded as a plot attribute to facilitate stratification using the GIS.

The "simple" solution is to use differential global positioning systems (GPS) to locate the plots, but this is not always practical. For example, in Bhutan the steep terrain makes plot location and field work very difficult indeed. Real time differential GPS is not suitable if the field crews do not have access to computers and power for weeks on end. However, Garmin GPS units can locate plots to within about ±250 m, given the selective availability adjacent to China and given the lack of a suitable Digital Terrain Model (DTM). Recording the time and the satellites used to locate the plot location on a piece of paper would later enable more accurate spatial positioning using differential GPS. This means that both nominal and so-called actual plot locations need to be recorded and stored.

Systematic sample comes at a cost because more samples are required than for the more statistically robust and efficient stratified random and multistage and multiphase designs. However, the ease of calculation and the ability to modify the stratification after field sampling are so important in many situations that the economic costs would seem to be justifiable where flexibility is required. A further advantage is the ease in determining whether all the samples planned to be measured are in fact measured because incomplete sampling shows up readily on a grid.

COMPLEX AND SIMPLE DESIGNS

Implementing a complex forest inventory design or research experimental design may save money, but forests change and the use of the information being collected may change, perhaps rendering a very complex and expensive project quite redundant.

One example in the intensively managed pine plantations in South Australia was a thinning/fertilizer interaction experiment. An economic analysis had shown that a very important economic advantage might be gained by modifying the thinning regime considered optimal economically if post-thinning fertilizer was applied. There was believed to be an interaction between the thinning and fertilizer application, and a complex and costly experiment was justified. In the large trial (O'Hehir *et al.* 1996), the accepted design for each site was 4 blocks by 12 fertilizer treatments by 3 levels of thinnings. The objective was 144 plots on each of four sites, each with 25 trees after the initial thinning. This requires a lot of field work, large areas of near uniform forest, and good mensuration and analysis to determine the effects. The initial results suggest that the interaction is not significant statistically but is significant economically. Analysis is continuing and is now the subject of a Ph.D. study. Originally one option—using simgle tree plots and more replicates—was considered to save space in the field and to reduce expense. This design would have been more complex to analyze because any extra growth would have changed the relative growing space, making it more difficult to develop the necessary model of the interactions although relatively easy to determine whether significant differences existed or not. In the end, the decision was made to use fewer replicates and 25-tree plots, the far more costly option.

Shortly after the first sites were established, the whole forest estate suffered an outbreak of Sirex (*Sirex noctilio*), and this ravaged some experimental sites, affecting some thinning treatments more than others. It has been possible, although somewhat difficult, to use the current plots to model the interaction. It would have been impossible to use the experiment if it had been designed as single-tree plots, because there would have been too few samples remaining after the Sirex attack.

Building this sort of flexibility into the original design may have been more expensive, but it was undoubtedly the best decision. Some apparent overkill is needed in the design every now and then.

INTEGRATING WOOD- AND NON-WOOD-BASED INVENTORIES

The GIS has been touted by some as providing the core reason for a paradigm shift in forest inventory design. If some spatial information cannot be effectively stored in a GIS, then it is not uncommon to hear the response "then why do you need it" as an excuse.

One of the best contrary examples I know is the Golpatta or Nipa Palm (*Nipa fruticans*) in the Sundarbans Reserved Forest in Bangladesh (Leech 1994, 1997). The Golpatta leaves are harvested annually and are vitally important for housing. There are some 40,000 to 80,000 ha of Golpatta in this forest, but all in discontinuous strips, generally no more than 5 m wide, along the banks of the khals or rivers. It is virtually impossible to map the Golpatta and therefore virtually impossible to use a GIS to store and manage the spatial information of this important resource. The most appropriate solution would appear to be to use the GIS to define broad ecosystem strata and then to use plots (measured spatially into forest, Golpatta, and water) to use the proportions of each land-use type to determine more accurately the area of Golpatta. The plot information also provides the necessary stocking information.

GIS technology is a very important and effective tool for forest inventory, but in some situations, it does not provide the complete solution to managing the spatial information.

LINKED STUDIES OR FULL INTEGRATION

Some years ago several organizations and authors proposed and implemented what were called totally integrated forest management planning systems. The primary advantage of this approach was that the use of one consistent planning approach for the development of forest management plans, making the planning holistic and generally very satisfactory.

The advantages of a fully integrated holistic system over the previous situation with many smaller separate systems are relatively obvious including better data integration; better systems integration; less costly field work because each visit to a plot obtained a wide range of information; good use of new technologies such as remote sensing; and minimal duplication of data, information, and effort. The advantages of having a totally integrated and holistic system were obvious. However, such systems have a few inherent disadvantages too that were not always fully understood. These systems are large and complex and therefore difficult to maintain, enhance, and eventually replace; they require a large commitment of manpower and resources; and they are less flexible when objectives and needs evolve over time. In the current general economic climate, large systems are often more difficult to finance.

A suggested alternative that makes sense in developing countries where objectives are often not clearly defined, and in many developed forests where information needs are continually changing, is to use a series of linked studies. Each separate project can therefore be justified and implemented separately, but it should be designed so that for a small overhead the information can be linked. This also has advantages in a country such as Bhutan where many forest management activities are funded by different donors, and it would be highly desirable to have one consistent coherent planning system for the whole country.

The objective then is to implement separate projects but to design them so as to facilitate integrated analysis. This requires commitment from the forest management authority to insist on the integration aspects, and it is acceptable only if the extra work involved has only a minimal impact on project feasibility.

INTEGRATION BETWEEN PROJECTS

The alternative to a large totally integrated system is to keep all projects completely separate, but this generally leads to the information not being able to be integrated at all. So complete integration appears generally unworkable economically, and completely separate independent projects generally lose information flexibility.

What appears to be needed is a linked series of studies, each of which could be justified, implemented, and analyzed separately and simply, but which would also be linked in ways that would facilitate analysis in a multidimensioned manner as well. The surveys do not have to be all be carried out by the one organization. In this way, the body of natural resource and ecological information about the forest area can be built up relatively simply. Basically four aspects to integration should be considered:

- integration between disciplines,
- spatial integration,
- integration over time, and,
- integration of data and information.

If one basic minimum core series of permanent sites is used as the basis for all studies in a complex ecosystem, this will assist integration between disciplines because a minimum set of consistent information can be collected by those people working in their different disciplines, and trend information will also become available. These sites can be augmented as any researcher deems desirable for a particular study, but a core set of permanent sites would be constant between quite different research projects. The integration must be both formal and informal with ongoing interaction between researchers.

In the Forest Resources Monitoring Project in China, the five disciplines (GIS, Remote Sensing, Field Inventory, Data Base, and Growth Models) were each led by specialist teams at four separate institutes (Beijing, Xi'an, Changsha, and Jinhua), although all teams were represented at each Institute. To succeed, the large project had to focus heavily on integration issues.

In one Bangladesh Integrated Management Project (de Vere Moss 1996), the challenge was to integrate specialists in zoology, botany, non-wood forest products, entomology, pathology, economics, silviculture, tourism, fisheries, and marketing, and to provide a sensible path for future development. This would have been a lot easier and more effective if the individual specialists had been instructed to use a core set of sites for each of their separate studies. Insisting on a minimum core set of sites for all disciplines would then allow future analysis across the information collected in each discipline and would facilitate analysis and integration of aspects that are not normally analyzed together. This enables different agencies or donors to fund different projects but still allow the information to be integrated.

Spatial integration is absolutely necessary. By ensuring that some sites are common between different projects, it will be possible to analyze quite disparate information sources and it may be possible to resolve quite important problems in this way.

Integration of information over time is essential for resolving many complex ecological and forest management questions. Various inventory projects in China, Myanmar, Indonesia, Bangladesh, and Bhutan have demonstrated to me how difficult it is to get time series trends, the trends that are essential if forest management planning is to be fully effective. A project-based approach with its necessary reliance on data collection at a single point in time is generally unable to provide this time series information necessary for good planning. Too often a new project changes the inventory design for some sound reason but at the cost of reducing the ability to get trend information. In one country, it was suggested by a consultant that the method of locating the grid plot centers should be changed from latitude and longitude to UTM (Universal Transverse Mercator) because this will ensure that each sample represents an equal land area. The gain is minimal compared with the loss of potential growth information in the short term.

It is highly desirable that all information, including information collected by different organizations, be integrated into the one set of database structures. The same idea of loosely integrated studies can be carried forward into integrating the information. One method is to insist on a minimum data dictionary for database fields and to insist on using one relatively simple but readily available database package. The various dBase-based database packages provide one way of achieving this. Most other high level programming languages can access dBase-structured files, so the overhead imposed through insisting on one database style is not exorbitant. This is obviously not the technically most competent computing solution for any of the separate analyses, and it does not look like a neat solution. However, the approach is pragmatic because it will minimize the cost overhead for individual projects and will enable the disparate databases to be linked.

ASPECTS OF INTEGRATING FOREST INVENTORY AND NATURAL RESOURCE SURVEYS

The Forest Resources Management Project (FRMP) in Bangladesh carried out a detailed forest inventory in the forest divisions to develop management plans for the production forest. The primary objective was to estimate standing volume of trees. Independently, a Natural Resources Survey (NRS) was conducted in the protected areas to survey vascular plants and vertebrate animals; the primary objective was to prepare species lists and to form some guidelines for developing prescriptions for conservation management. Integrating the information from these two surveys was difficult because the area bases are different, the objectives were different, and the data collected were also different. What was needed by the project was an integrated management plan that effectively integrated these two information sources.

An Extended Natural Resources Survey (ENRS) was designed and implemented very satisfactorily by the Forest Department in Bangladesh and reported by Leech and Ali (1997b). Table 1 summarizes the essential features of the three surveys. It can readily be seen that the ENRS provides information linkages to both the forest inventory and the NRS and enables comparisons to be made. Without the ENRS, it would have been impossible to effectively prepare an integrated management plan because there were no information linkages between the Natural Resources Survey and the forest inventory.

THE SUNDRI DIEBACK PROBLEM IN THE SUNDARBANS OF BANGLADESH

The Sundarbans Reserved Forest in Bangladesh is the largest contiguous mangrove forest in the world and covers over 400,000 ha of land. The main tree species are Sundri (*Heritiera fomes*) and Gewa (*Excoecaria agallocha*). The ecosystem is obviously very fragile but it is vitally important to the psyche of Bangladesh because it is the home of an estimated 300-450 tigers (*Panthera tigris*). Some 2.5 million people live with 10 km of the SRF and the socioeconomic pressure is great. The Sundri is interesting in that within a very short distance you can see Sundri trees with young leaves, old leaves, and trees suffering a mysterious dieback with thin crowns and dying leaves. I have not yet seen an effective use of remote sensing in this situation; the reflectance differs

Table 1.—*FRMP: Forest Resources Management Project in Bangladesh*

NRS: Natural Resource Survey	ENRS: Extended Natural Resource Survey	Forest Inventory
• 13 Protected Areas	• 8 FRMP Divisions 2 Candidate Protected Areas	• 8 FRMP Divisions
	• 11m circular plots 4 2x2m subplots	• 11m circular plots
• Gradsect (gradient directed transect) oriented across the habitat gradient	• 3 plots 100m apart oriented across the habitat gradient	• 5 plots 50 m apart in a fixed cross
• Arbitrarily selected sites to cover habitat gradient	• Randomly selected from systematic sample of inventory plots	• Systematic sample
• Not stratified	• Stratified	• Stratified
• Observations on gradsect and on the general area	• Observations on plots and on general area	• Observations on plots
• Objective was to maximize species counts	• Objectives are an unbiased estimate and species counts	• Objective was an unbiased estimate
• Vertebrate Animals Vascular Plants	• Vertebrate Animals Vascular Plants	• Trees and productive plants
	• Trees N, BA • Woody plants: N	• Trees: N, BA, Vol • Bamboo: N • Nipa: N
• Plants: Presence • Animals: Presence	• Other plants: Presence • Animals: Presence	
• Qualitative	• Qualitative • Quantitative	• Quantitative

without any change in vegetation and does not change when the vegetation observed on the ground does change, although there should be scope for submeter pixel resolution imagery to help interpret what is happening. Upstream in India is the Farakka Barrage, which has reduced the amount of water released through this large mangrove ecosystem.

Sundri dieback in the Sundarbans has been known to exist for many years. Different experts have suggested that the cause is salinity, changes in salinity, fungal pathogens, insect attacks, accretion, and sheet erosion. It would seem that all possible causes that appear to fit the distribution pattern are bedeviled by contrary examples. The problem of determining the cause or causes seems intractable, and there is insufficient expertise and little funding available to pursue the subject. In a joint paper with Mr. Syed Salamat Ali (1997a), we acknowledged that we do not have any answers but suggest that the best chance for determining the cause and then the most appropriate management strategy is to adopt a resource survey strategy that allows the separate specialists to conduct their own research programs but to insist that this is done in such a way that allows later integration of these disparate studies. This can be done by insisting on sampling at specific sites in addition to the sites selected by the researcher, and we suggest using 5-foot sites because these are compatible with the extensive forest inventory (1-foot sites of a cluster of five circular plots) and the Extended Natural Resource Survey (Leech and Ali 1997b) that used the subset of 5-foot sites. The Forest Department has a resources information management system, which is integrated with a geographic information system and can thus provide a way of integrating all the information on one facility and so assist any integrated analysis.

It would be impossible to design and implement one single experimental strategy aimed at resolving the issue; the many alternative hypotheses and possible causes make such a venture an exercise in futility. However, it is possible to implement separate specialized studies. What is needed are the linkages.

The existing knowledge led us to conclude that there appears to not be one single simple cause. Several different factors seem to combine to provide the circumstances that lead to Sundri dieback.

MEASUREMENT STANDARDS

If separate linked studies are to be effectively integrated, then the measurement standards used for any study must be appropriately defined, clearly stated, and well documented. This has generally not been well done in many past surveys. There is also a need for control enumeration to ensure that the collected data are reliable and precisely measured and that the measurement precision can be determined. Without this information about the precision of past surveys, it is difficult to effectively carry out analyses integrating disparate data sources when access to the people who carried out the earlier surveys has long since become unavailable.

SUMMARY

Not one single inventory design is appropriate for all circumstances. An inventory designer must consider the specific objectives that have been set and must understand the strengths and weaknesses of the various component technologies. Flexibility costs money, but experience suggests that this is money well spent.

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