

Documentation of Indigenous Pacific Agroforestry Systems: A Review of Methodologies¹

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Abstract: Recent interest in indigenous agroforestry has led to a need for documentation of these systems. However, previous work is very limited, and few methodologies are well-known or widely accepted. This paper outlines various methodologies (including sampling methods, data to be collected, and considerations in analysis) for documenting structure and productivity of indigenous agroforestry systems, using references to previous documentation studies carried out in other parts of the world.

Interest in indigenous agricultural systems has grown enormously in the past decade or so, largely as the result of the shortcomings of the "green revolution." The realization that many traditional systems are well integrated ecologically, economically, and socially at the local level has given a new impetus to research. Also, these systems offer valuable insights into adaptations to local environmental and cultural constraints. There is also a strong possibility that research into these agroforestry systems will lead to their improvement in terms of production and other development needs of the respective islands, and that information gained will be valuable in finding solutions to agricultural research problems in other areas. As a result, many scientists now see indigenous agriculture as dynamic systems which can serve as foundations for development efforts rather than as static obstacles to agricultural intensification.

Unfortunately, due to largely being ignored in the past, research methods for studying indigenous agriculture have only just begun to be developed. The inherent difficulty in studying indigenous agriculture systems is the relative complexity of traditional mixed cropping systems compared to "western" agricultural practices. Indigenous agroforestry systems are the product of both natural and anthropogenic influences, so they are different than either natural ecosystems or modern agricultural ecosystems. Current research methods developed in various disciplines such as vegetation ecology, forestry, and agronomy need to be combined in their study. Collection of data from indigenous agroforestry systems is further complicated due to the lack of existing data on many indigenous crops and animals, the long-term nature of the perennial components, the subsistence nature of many agroforestry products, and the variation within and between farms and regions. Cultural practices and restrictions can also hinder research work in some areas. Finally, the lack of trained manpower and financial constraints must also be considered in any research project in developing countries.

In the Pacific, most work, with a few exceptions (e.g., Handy 1940; Barrau 1958, 1961) has been in the form of general descriptions, with agriculture serving only as a component of the

more general social or economic systems. Other work has focused on strictly botanical studies of natural or cultural vegetation (e.g., Fosberg 1959). It is not until quite recently that a concerted effort has been made to systematically and quantitatively analyze traditional Pacific island agriculture (e.g., Thaman 1975, Manner 1976, Raynor 1989).

The goal of initial research should be to develop a general quantitative overview of the local indigenous agroforestry system. Among the data desired are floristic composition, vertical and horizontal structure, and phenology of agroforests, as well as information on production, seasonality, and yields of major products. Often, related information on farmer and farm family demographics, land use and tenure, and labor input and allocation is also desired.

Methods for Characterizing Structure of Agroforestry Systems

The initial focus of studies of indigenous agroforestry systems should be to characterize basic agroforest structure. Ecosystems have three basic structural components—vertical, horizontal, and temporal (Whittaker 1975). Vertical structure is the height and stratification of plants in the system, depending much on the floristic composition and light relations within and between species. Horizontal structure is the vegetation organization on the ground, affected by the environment, species interrelationships, and human management. Temporal or time relations include the phenology, age, and long-term development of the agroforest stand.

Sampling is a key consideration in collecting indigenous agroforest structural data. It is usually impossible to measure the entire area where a system is practiced, so data must be recorded for samples of the agroforest, and then extrapolated to the larger area. Sample size also affects the precision of estimates obtained by sampling. A larger sample size gives greater precision, but often constraints of time and money limit the number of actual sampling sites.

Selecting an unbiased sample is also important, especially if results are to be extrapolated to the general population. One way to generate a random, unbiased sample is the selection of sampling points (farms) on a map using a coordinate grid and random numbers. If areas to be studied are large, farms can be selected first using this method, then a systematic sub-sampling lay-out of smaller plots can be employed at each farm.

Sampling Systems

Sampling methods are numerous, and can be categorized into plot or plotless methods (Mueller-Dombois and Ellenberg 1974). Plot methods involve the use of a releve, quadrat, circle,

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or other type of two-dimensional sampling area. Plot size depends on the type of vegetation to be sampled and the spacing between them. Larger vegetation needs larger plots. Plots are randomly or systematically placed in several places within the sample area. In some cases, the "plot" might be the entire farm. Transects are a type of plot with greater length, usually placed across a gradient (i.e., elevation) to get some type of measure of vegetation changes over the gradient being considered.

Plots have been used to measure agroforest in some studies. Manner (1981) used small 5 x 5m quadrats to measure biomass productivity of gardens in the Solomon Islands. Thaman (1975) used the whole farm as a plot and counted tree species occurrences on 101 Tongan farms. Jacob and Alles (1987) did the same on 30 farms in Sri Lanka. Advantages are that many different measurements can be done on plots, they can be easily remeasured (if permanently marked), and lend themselves well to long-term studies. Disadvantages are that plots can be time-consuming in laying out and measuring.

Plotless methods have been developed more recently. These consist of line and point methods. The line-intercept method was developed as a measure of cover, to eliminate the subjectivity of visual methods of estimation. A line, wire, or measuring tape is placed randomly within the agroforest, stretched and held tightly along the ground, or at some selected height above the ground. The distance along this line overlapped by each plant is recorded as cover for that plant. Individual cover measurements are summed to estimate total cover. Advantages for this method is that it is relatively simple and quick. Disadvantages are that it is not always accurate due to overestimation due to inclusion of foliage interstices, or underestimation due to over-looking of multiple vegetation layers.

Several point methods have been developed. Perhaps the point-intercept method, developed by Curtis (1959), is the most well-known. This method is characterized by the use of point samples, rather than fixed areas. It is used to determine space/plant, rather than plants/unit area, as in plot methods. First, the sampling area is assessed for homogeneity, then the first point is determined randomly. A compass line is laid out, and points are laid out along that line at a fixed distance. Data is then recorded at each point. Data can consist of cover, stratification, and distance measurements. Several methods have been developed, the most reliable being the point-centered quarter method (Mueller-Dombois and Ellenberg 1974:109-112). Basically, four quarters are established by two lines, one, the compass line, and the other a perpendicular line through the point. Then the distance from the point to the nearest individual tree in each quarter is measured. These distances are summed and divided by four times the number of points. This will give the average distance (D) between trees and $D^2 = \text{mean area/tree}$.

In forest surveys, a more common method, known as variable probability sampling or the Bitterlich method (Mueller-Dombois and Ellenberg 1974:101-106, Dilworth and Bell 1977), is used. Points are laid out in much the same way as in other point sampling techniques, but a prism is used to decide what trees will be sampled and which will not. This results in a variable plot size, trees of a larger diameter being more likely to be part of the sample at distances further from the point. This

method not only allows quick determination of sampling trees, but it also allows for a calculation of tree basal area per unit land area. This is very useful in volumetric surveys, and basal area can serve as a measure of species dominance. With additional equipment, DBH of sampling trees can be measured (with a diameter tape) and height (using a relaskope or similar instrument). Other observations can be recorded during the survey. The point intercept methods are quick and easy in the field, and thus larger areas can be surveyed than with plot methods. Their disadvantage is that they are not always as accurate as plot samples.

Choice of sampling methods depends on types of data desired, the morphology of the vegetation, its pattern, and the time available (Moore and Chapman 1985). For agroforest, sampling techniques must take into account both perennial tree and shrub species and annual undergrowth species. For this reason, combined methods will tend to give the best results. Foresters often combine point intercept sampling for trees with plot sampling for undergrowth. Curtis (1959) used a point intercept method combined with the point-centered quarter method in his landmark survey of the vegetation of Wisconsin. Thaman (1975) used whole farm plots for trees and small quadrats for annual crops on Tongan farms.

Types of Agroforest Structure Data

Species presence is the most basic and most-often collected data on indigenous agroforest systems. This involves a species inventory, in which all species present in a defined area are recorded. This is a relatively easy variable to measure, and does not require plots or other techniques. Species presence gives a measure of frequency of occurrence of plant species over all farms. Generally, species presence has been the first step in nearly all traditional agroforestry studies (Thaman 1975, O'king'ah and others 1984, Balasubramanian and Egli 1986).

Cover, defined as the vertical projection of crown or shoot area of a species to the ground surface, expressed as a percent of the reference area (Mueller-Dombois and Ellenberg 1974:80), is another often used measure. The amount of cover provided by a species is directly related to its ability to compete for and convert various resources (nutrients, water, and sunlight) into above and below-ground biomass (Conant and others 1983:365). As such, cover is of greater significance than species number, since it expresses major light/stand effects. Cover is often estimated by visual methods on relevés, plots, or transects. Generally, percent cover is expressed in classes, as in the Braun-Blanquet Cover Abundance Scale (Mueller-Dombois and Ellenberg 1974:59-60):

- 5 - >75 percent of reference area
- 4 - any number, with 50-75 percent cover
- 3 - any number, with 25-50 percent cover
- 2 - any number, with 5-25 percent cover
- 1 - numerous, <5 percent cover
- + - pronounced few, with small cover
- r - solitary, with small cover

These classes add accuracy to sampling as it is relatively easy to differentiate between them. The short-coming of the

Braun Blanquet method is that it does not take into account different canopy levels. In agroforests with complex species mixes, it is also necessary to stratify species by cover, for example:

T = tree layer	>5 m high
S = shrub layer	S1 - 2-5 m
	S2 - 50 cm-2 m
H = herb layer	H1 - 30-50 cm
	H2 - 10-30 cm
	H3-<10cm

These categories can be rearranged or changed depending on the goals of the researcher. Michon and others (1983) collected cover and strata data from 20 x 40 m transects to do an architectural analysis of two Java homegardens. In agroforest studies, it may be useful to classify species or individuals by height, i.e., canopy spp. (>10 m), subcanopy spp. (5-10 m), and understory spp. (<5 m), as Haun (1984) did in a study of Pohnpei vegetation. Cover and strata classes can be decided during initial reconnaissance, then estimated by visual and height measurements.

Species density is another important measure, and is the count of individuals of species within a sampling area. It is the measure of relative abundance of different species. Counts of large species are most easily done on large plots (i.e., a whole farm), but counts of small abundant species become very difficult on large plots. Density measurements can also be calculated from plotless sampling techniques as indicated above, with fairly good accuracy. For agroforests, species density can be used to estimate the relative importance of different species to the overall crop mix. Species counts are often done on the farm-level (i.e., Thaman 1975, in Tonga; Jacob and Alles 1987, in Sri Lanka.)

Frequency is defined as the number of times a species is recorded in a given number of plots or at a given number of sample points. It is generally expressed as a percent, and is easily calculated. Waddell (1972) in New Guinea, Thaman (1975) in Tonga, and many other investigators have used frequency as a measure of the relative importance of various crop species to the local agricultural system.

Dominance is measured from the stem cover or tree basal areas of the tree species in the sample stand. Basal area is the area outline of the plant near the ground surface. It can be determined by the formula:

Basal Area = $(1/2d)^2 \times \pi$, where d stands for diameter.

Basal area is easily calculated by the Bitterlich method. Height is also used as a measure of dominance, especially in forestry surveys.

DBH (diameter breast height), which is a measure of tree diameter at 1.4 m height, and **tree height**, which can be measured with instruments or by trigonometric calculation are other measurements that are useful in agroforest structural inventories. These can be useful in later analyses, and can form important variables in allometric equations relating them to tree growth or yields.

Temporal Patterns

Temporal structure exists in indigenous agroforestry systems in both short-term (phenological or seasonal aspects) and long-term (development or successional aspects). Seasonality (or phenology) can be characterized by observation during field visits and/or periodic market surveys. Such data as time of flowering, fruit development, and time of harvest provide valuable information on the short-term temporal aspects of the agroforestry system. For important species, recording of seasonality for individual plants can be carried out by several cooperating farmers. An effort to note seasonal differences between cultivars should also be made on crops for which numerous cultivars exist.

Long-term development or successional aspects are more difficult to characterize, since they generally occur over periods much greater than a single year. One example is the swidden/fallow cycle in slash and burn systems. Temporal changes also occur in more permanent agroforestry systems as a type of "farmer-controlled succession" (Michon and others 1986). Characterizing these long-term temporal patterns is often important in indigenous agroforest studies. It is usually not possible to observe individual plots over long periods of time, so individual farms or plots can be categorized into various age groups and then compared and analyzed.

Related Information

Traditional agroforestry systems are often times highly variable not only in terms of species and structure, but also in terms of the environment in which they are found. These environmental gradients affect structure of the agroforest as well as management and production. They affect the determination of the sampling unit size in that the gradients should be relatively homogeneous within a single sampling unit. Some related site information that should be collected include:

Climatic factors - rainfall, temperature, and insolation are important variables, and often change over gradients, especially elevation.

Topography - Slope, slope exposure, and elevation can have major effects on agroforest structure and yields. Slope partially determines the erosion risk as well as other limitations on cropping. Slope exposure can affect incoming solar radiation and thus productivity. Elevation and climatic effects have already been discussed. Slope gradients can be measured using a simple clinometer and classed as follows: 0-10 percent, 10-25 percent, 25-50 percent, and over 50 percent. On individual farms, the slope also assists in separating homogeneous sample units. Slope exposure can be recorded with a compass, and elevation can be recorded from good topographical maps, if available.

Soils - structure, type, pH, and fertility are important soil variables that will affect agroforestry. Soil surveys have been completed for many areas and can be used as the main guide to soils in the sampling areas. Farm maps can be superimposed on the soil map to get general soil types. Generation of detailed soil information is often hampered by time constraints and lack of

laboratory facilities. If possible, probably the most useful and economical (in terms of effort) soil measurement to collect is pH, either measured with a field kit or from samples collected in the field and sent to a soil testing laboratory.

Management - the human factor is the key variable in managed agroforestry systems. Management consists of all the inputs into the agroforest in order to maintain or increase production. In most traditional agroforestry systems, the main input will be family labor, especially during key planting and harvesting times. Weed control (generally by bushing with a machete) and regular harvesting make up the remainder. Management in traditional agroforestry can be measured as a function of labor input, as determined by measurement and observation, and weed pressure, in the form of weed cover and height, measured visually in sample areas. Notes can also be made on animal grazing pressure, disease or pest presence, and distance of plot from main house.

Related information on farmer and farm family demographics, land use and tenure, and labor input and allocation can be recorded by interviewing the farmer informally before the actual field survey. This not only gives the researcher a better overall view of the local farming system, but also provides some time for the farmer and researcher(s) to get comfortable with each other.

Cultural Considerations

Researchers of indigenous agroforestry systems often also face certain cultural constraints. These must be carefully considered along with the technical aspects discussed above, and research methods should be designed accordingly. Farms selected can be visited in advance, and the research project explained thoroughly to the farmer and his family. Plot surveys can be designed to be fast and simple, so that only a few people are needed to carry out the field work. Having local agricultural and forestry staff assist in field work not only assures that survey results will have a greater impact, but also can lead local officials to a new appreciation of indigenous agriculture.

Animal Component

Equally important, but often overlooked in studies of traditional agroforestry systems is the animal component. Animals interact with the agroforest in many ways, especially through the recycling of excess yield and plant parts into organic manures. Free-run livestock allowed to graze interact more strongly, but even penned livestock consume agroforestry products. Waddell (1972), in his study of the Enga of Papua New Guinea, made counts of livestock at the farm level, and also kept track of food consumption of the most important animal, pigs. Other important information to be collected includes animal management (penned, fenced, or free-run) and some assessment of beneficial or negative interactions of animals with the agroforest.

Methods for Determining Input-Output Relations

Characterizing the structural dynamics of an indigenous agroforestry system is only a part of understanding and evaluating that system. A measure of the relative efficiency of that system as a production method must also be developed. In order to do so, inputs (in terms of labor, management, and capital) and outputs (yield of products) must be measured. This is difficult in many of these systems because farmers do not keep records, unpaid family labor is often the main input, and few products reach the market. Often, these traditional systems are characterized by elaborate distribution systems. It is thus understandable that few researchers can meet the time and expense involved in accurately quantifying these important variables. The following discussion centers on possible methodologies for overcoming these constraints.

Measuring Input

One of the most popular methods of measuring input into agroforestry systems has been the use of farmer surveys. These surveys are made at regular intervals, and farmers report to the researcher on their activities (as well as crop production and marketing). A variation on this has been the use of record sheets, given to the farmers and collected at regular intervals, on which the farmer records his activities and production. The problem with both of these methods is that they can be very unreliable, and depend on both the farmers cooperation and honesty. Jacob and Alles (1987) have attempted to overcome these inaccuracies by reporting time spent in various activities as a percent of total time, rather than an absolute hour value. The added problem of seasonal variability further complicates this process. Most researchers have been satisfied with assuming that all family members are fully employed, and then computing labor availability as a function of household members and their abilities.

A second more precise way is by the use of Time Allocation (TA) studies. This is a tool developed by anthropologists to study the use of time in different cultures (Kronick 1984.) The methodology has recently been reviewed by Gross (1984). He stresses the importance of defining the sampling universe (population), unit (i.e., household, individual), duration, and frequency. These depend much on the goals and time available to the researcher. Presently, a random spot-check method is the most widely used, in which a researcher visits the farm at random times and then records the activity of each family member upon his arrival. Studies generally last for at least a year, and frequency of checks determines the precision of the final product. If some information is already known about seasonality of labor requirements, more frequent visits can be made at peak times, with less frequent visits made in the off-season.

In some studies, certain undertakings have been timed, such as clearing, planting, and harvesting, and then these related to unit area to get an estimate of total labor expended in various tasks. This data can be used by itself or in conjunction with surveys or TA studies to complement and check data.

Measuring Output

Yield in traditional agroforestry systems is difficult to measure for reasons already discussed. As such, it is relatively rare to find indigenous agroforestry yield data in the literature. A few recent studies have made estimates of yield using various methods, and these will be discussed.

Several researchers have used farmer surveys and record sheets in yield studies (e.g., Lagemann and Heuvelink (1983) on 68 farms in Costa Rica for one year, Fernandes and others (1984) for 30 farms in Tanzania, Balasubramanian and Egli (1983) in Rwanda). These surveys are relatively easy to do and are inexpensive. The disadvantage is that they depend heavily on farmer memory, which is prone to error. To overcome this, other researchers have lived in an area and weighed produce as farmers come in from the farm each day, or have paid an assistant to do so (e.g., Waddell (1972) in New Guinea, Fairbairn (1979) in Western Samoa, and Michon and others (1986) in Sumatra). While this method gives more reliable data, it is limited by time and expense to smaller sample size (i.e., one or two villages). It is also difficult to use this method in areas where people live in scattered homesteads, rather than villages.

Market studies have been used in some studies to measure production, but in subsistence agroforestry systems they are not reliable since most produce does not reach the market. These studies can, however, be used to check seasonality of various crops on the assumption that at least some farmer will always be bringing in some of the produce they have available.

Plots have been used in several studies, where random plots are set out on farmer's land, and then all species are harvested, measured, and weighed during the study period (Manner 1976 & 1981, Beer and Sommariba 1984). These types of measurements are very reliable, and lend themselves extremely well to productivity (biomass) studies. They can be expensive and time consuming, however, and it is often hard to get data from tree crops which tend to bear over an extended period. Manner (1976 & 1981) employed allometric equations to measure productivity of larger species.

Individual species measurements can also be used, and were the basis of a recent detailed study of breadfruit production on Pohnpei (Raynor 1989). Representative numbers of individual plants or trees are tagged, and then harvest weighed and recorded throughout the study period. This method could be especially useful in comparing different varieties of a crop species, as well as giving the added benefit of phenological data. It is also relatively easy to compare physical measurements, i.e., d.b.h., height, and canopy size, with yield through regression analysis. Some questions of sample size and representativeness need to be answered, although 20 individuals is suggested as a minimum.

Besides predictions based on allometrics, there are possibly other methods that could be used to measure yield. It may be possible to count immature fruits on trees and relate it to yield, or to relate individual species densities to yield (as is done in monocropping). There is also little doubt that indigenous people have their own systems of yield prediction, based on weather, phenological characteristics, or other such observations. Since

an important part of many studies is yield measurement, collection of traditional knowledge in this respect should be an integral part of the project.

The last consideration with yield is annual fluctuation. There is no doubt that annual fluctuations in yield do occur in tree crops. Very little is known about the physiological basis for this yield fluctuation in many traditional crops, but it is most certainly affected to a great extent by weather. Unfortunately, most research projects are undertaken for periods of a year or less, and as such, yield data can be somewhat misleading. The random selection of farm sites and the distribution around the island will minimize local abnormalities, but only continuous data collected over several years can give accurate estimations of yield for most crops.

Conclusions

Documentation is an important first step in researching indigenous agroforestry systems. Through increased study of these systems, they can act as a foundation for future agricultural development, and technologies and crops developed over thousands of years can continue to serve people into the future.

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