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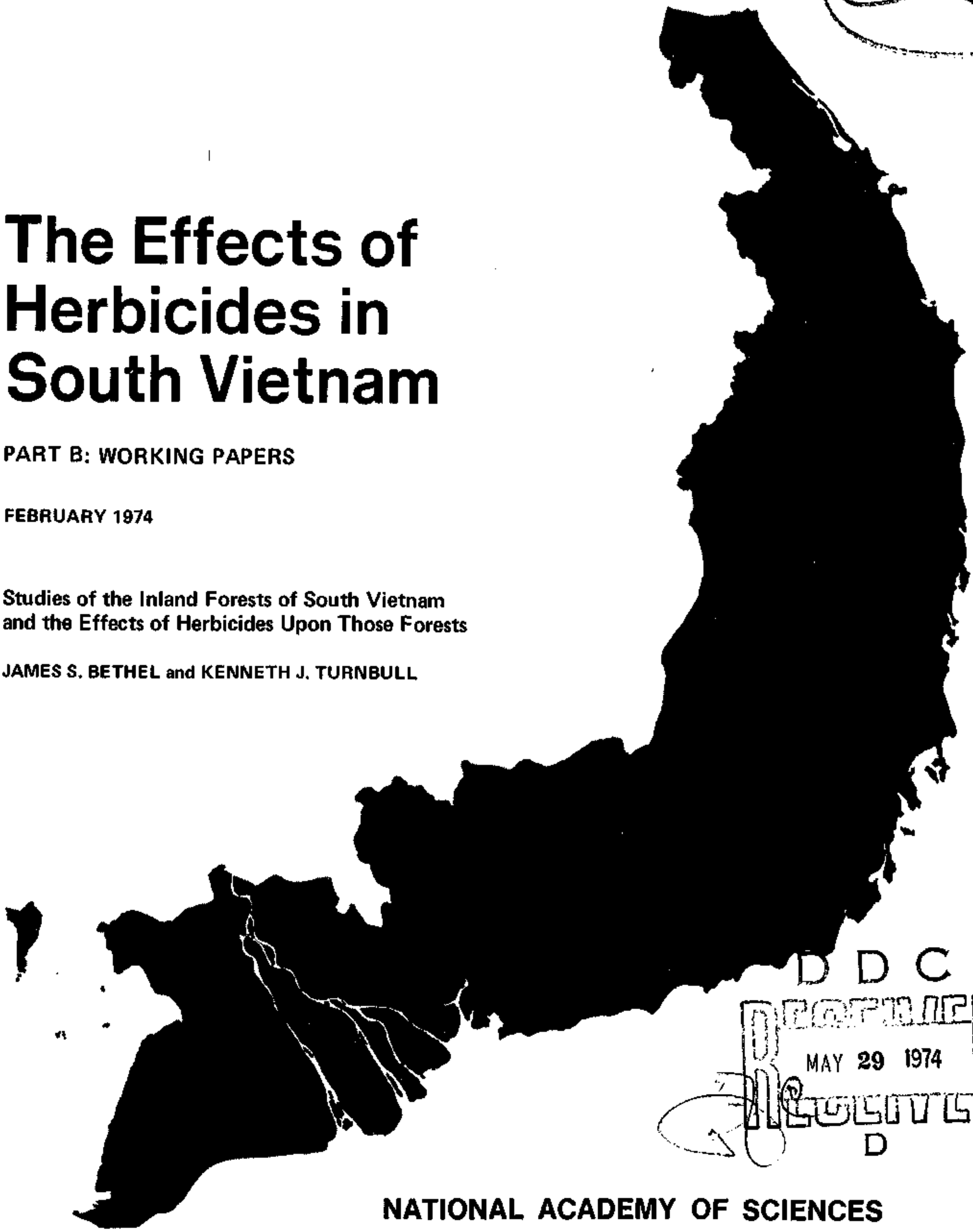

The Effects of Herbicides in South Vietnam

PART B: WORKING PAPERS

FEBRUARY 1974

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and the Effects of Herbicides Upon Those Forests

JAMES S. BETHEL and KENNETH J. TURNBULL

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WASHINGTON, D.C. 20418

Studies of the Inland Forests of South Vietnam and the Effects of Herbicides Upon Those Forests

This is a collection of background papers that describe the basis for the analysis of damage to the inland forests of South Vietnam. These studies were conducted by a forestry study team under the chairmanship of James S. Bethel, a member of the NAS Committee on the effects of herbicides in Vietnam. The forestry study team was constituted as follows:

James S. Bethel	Chairman
Kenneth J. Turnbull	Vice-Chairman

Forest Characterization:

Jose Flores
Sanga Sabhasri
Sowsak Sukwong
William Hatheway
Joseph O'Leary
Charles Wick
Manuel Contreras

Damage Assessment:

Charles Peterson
David Briggs
Joseph O'Leary
Louis Kelley
Bruce Burwell
William Yeager

Special Area Studies:

David Briggs
Jose Flores
Robert Wadsworth
Charles Wick

I. Introduction

The task of the forestry study team was to examine the impact of military defoliation in Vietnam upon the inland forests in terms of their short-term and long-term utility as sources of materials useful to the nation and its people.

The greatest concentration of the defoliation missions of "Operation Ranchhand" directed at the inland forests of South Vietnam was in Military Region 3 (reference map). Accordingly, early in its deliberations, the Committee agreed to limit its detailed examination of defoliation mission impact as it related to inland forests to those located in Military Region 3. Approximately fifty-seven percent of all herbicide missions flown were located in whole, or in part, in this region consisting of 11 provinces.**

It was the objective of the Committee to collect and assemble the best information possible concerning the impact of military use of herbicides in South Vietnam and to analyze these data. It should be observed that war, wherever it has been fought, has commonly resulted in major impact upon forests and their future utilization. War in Vietnam, continuing more or less for over 30 years, has clearly been no exception. Some of the major battles of World War I and World War II were fought in forests, and the impact of the military activity upon those forests was great. The same phenomenon has typified other wars. The methods of warfare change over time, and war impact upon the forests also changes. Because of the long duration of the Vietnam conflict, there have been many changes in military impact on the forests in the course of its development.

** Military Region 3 comprised the provinces of Bien Hoa, Binh Duong, Binh Long, Binh Tuy, Gia Dinh, Hau Nghia, Long An, Long Khanh, Phuoc Long, Phuoc Tuy, and Tay Ninh.

The use of Rome ploughs to clear roadside forests is a successor to other roadside forest clearing operations undertaken in the decades of the Forties. Many of the forests damaged by the bombing and shelling of the 1960's undoubtedly contain within the trees, fragments of shells and bombs that are the residues of the earlier warfare.

The extent of the impact of war activity upon forests and their utilization is a function of the character of the forest at the time of impact. Accordingly, studies of past war-forest interactions, particularly in other regions of the world, are of little value in dealing with the present case. In the past, assessment of war damage to forests and forestry has usually been made after the cessation of hostilities when access to the forest was readily available and where field studies and experimental observation were feasible. The NAS Committee was given the task of undertaking an impact study while military action continued, where forests understudy were still being contested militarily, and where access to the forests on the ground was very limited indeed. This imposed very severe and obvious restrictions upon the investigators and their investigations. On the other hand, early study has the advantage of permitting some observations before the passage of time obscures the evidence of impact. Accordingly, the study was pursued with a full awareness of the limitations imposed upon it but with every effort made to take advantage of early observations no matter how limited they might be.

To be specific, this impact study was based upon aerial photographic evidence of the status of the inland forests as of the winter of 1972-73 in terms of the treatment of those forests with defoliants during the period from mid-1965 through early 1971. The study team developed its inquiry in such a manner as to permit its extension and validation in the future when more intensive field observations were feasible.

Early in the investigations, the study team recognized that it had a unique opportunity to assemble and use aerial photographic information concerning the inland forests. This was possible because the military forces had developed for their own purposes massive quantities of aerial photographs whose coverage included forest stands in the study areas. In addition, it was possible to have special photographic missions flown for the use of the study team. Without doubt, Vietnam forests are documented in terms of aerial photography more extensively than any other forested areas in Southeast Asia.

The problem which the study team faced in utilizing this photographic evidence was the lack of ground based information. Original forest inventories were lacking. Lacking, too, was any record of permanent sample plots in South Vietnam that could provide forest stand composition, growth, and yield data. The study team did, however, recognize that there were elements of commonality among the forests of Southeast Asia regardless of political boundaries and jurisdictions. Accordingly, the study scheme made maximum use of the aerial photographic evidence with respect to Vietnam and maximum use of forest stand composition, growth, and yield information for similar forest stands in the surrounding countries. The ground truth information was obtained from review of literature and from records on forests of Thailand, Cambodia, Malaysia, Indonesia, and the Philippines.

In addition, a research team from Kasetsart University in Thailand, under the direction of Vice Rector Sanga Sabhasri, established a number of growth plots, made remeasurements of other established plots and conducted field studies related to forest succession following disturbance. Photogrammetric measurements made on special low-level photographic sample strips in Vietnam and tree stem data obtained from sawmills and log assembly points in Military Region 3 were used to provide reasonable assurance that the ground truth data were appropriate and applicable.

The original objective of the Inland Forest Study Team was to assess the impact of herbicide treatment on the inland forests in terms of damage to merchantable timber. Botanists and ecologists on the NAS committee were concerned with the damage to the forests in strictly biological terms. They have addressed this subject in other papers prepared by the committee. It developed, however, that only the mangrove forests were sufficiently accessible to permit general ecological studies. Since the inland forests comprised the major area impacted by the herbicides and were the target for most of the herbicide that was sprayed, the National Academy of Science felt that some quantitative assessment of impact beyond the merchantable component of the forest ought to be made. Accordingly, late in the course of the study, the forestry team was asked to extend its investigations to cover damage to trees including the non-merchantable components of the forest. The same limitations on access that inhibited the biologists also presented problems for the forestry team. Nonetheless, an effort was made to cover this additional area of inquiry.

Damage to forests can take a variety of forms: a) loss of mature timber, b) loss of growing stock, c) loss of growth, and d) loss of seed source. Given the limitations of time and accessibility, these various forms of loss were susceptible to different levels of precision in estimation. The basic tools of the forestry team were a variety of kinds of aerial photographic coverage. Information obtained from these aerial photographs was augmented by ground data for comparable forests in other areas of the region where the forests were accessible. These included forest inventories developed by FAO for Cambodia east of the Mekong River, and Northeast Thailand west of the Mekong River. Also useful as a basis for forest structure and growth assessment were data from permanent sample plots variously located in Thailand.

Damage to the mature timber was most susceptible to quantitative assessment. As will be developed later in the report, however, the forestry team concluded from its investigations that other forms of damage were probably much more serious and longlasting. While the task of the study team was to evaluate damage caused by herbicides, it became clear as the study progressed that damage due to other forms of war activity was also severe; more severe and longlasting in terms of the long-run productivity of the forest than that due to herbicide use.

Herbicides were sprayed over large areas of the inland forests during the years 1962 to 1971; the heaviest herbicide operations were conducted between 1967 and 1970. During and since the period of herbicide spraying, the forest areas were subjected to other military actions such as bombing, shelling, land clearing and burning. Land was cleared to reduce ambush danger along highways. Forests were burned to improve visibility and reduce the danger of ambush by opposition troops.

The intended effect of military spraying of herbicides was to remove the leaves from the trees, making enemy troops and trails, arms, dumps, etc. used by them visible from the air. Fire was commonly used for the same purposes. In fact, forests that had been defoliated, whether or not the trees had been killed, were particularly susceptible to fire because of the presence of large quantities of highly inflammable fuel. They were commonly burned to improve visibility. Bombing and shelling in defoliated forests frequently ignited fires.

In addition to the various military impacts, these same forests also were used by the endemic population for non-military purposes. They continued to be harvested for timber and fuelwood and cut and burned to provide agricultural clearings. These harvesting and agricultural activities have been applied to the forests of South Vietnam for centuries, although the recent military operations have modified them to a varying degree in location and intensity.

The composition, structure, and behavior of forest ecosystems such as those that occur in South Vietnam are influenced and modified when they are impacted by human manipulations. These influences may be minor and difficult to detect if the manipulation is at a low intensity, and may be major and very obvious if the manipulation is at a high intensity. The duration of the effect may be short or long, depending upon the intensity of the manipulation. When a forest ecosystem is subjected to a great many manipulative events over a long period of time, occurring on different time sequences, the status of the ecosystem at any given point in time is a function of the combined prior impacts. Human-induced forest manipulations are not mutually exclusive events. They interact with each other, reinforce each other and compensate for each other in their forest ecosystem impact.

The forests of Vietnam have been utilized by man in many ways for centuries. Their present structure is a function of the basic vegetative type determined by biotic and abiotic factors and modified by a long history of human use. This then is the setting in which the evaluation of the effect of herbicides upon the inland forests of South Vietnam had to be pursued.

Clearly, the impact of military herbicide use in the period 1965-1970 reflected the varied status of the forests involved which, in turn reflected their prior histories as previously noted.

Inhibited by the absence of a forest inventory and the inability of the inland forest study team to conduct intensive and detailed on-the-ground investigation of the affected forests due to security limitations, the study team adopted the following evaluation strategy for achieving its goal:

1. It was recognized that nature does not observe political boundaries and that the forests of Southeast Asia including Indonesia, Malaysia, the Philippine Islands, Vietnam, Cambodia, Laos, and Thailand have much in common. Review of the literature of all these areas provided a much broader information base than would have been possible if the base had been confined to Vietnam. Indeed, the forest resource research base for the countries of Indochina was much less adequate than that of the surrounding countries. Since the other areas studied surrounded South Vietnam, it was possible to evaluate geographical trends and to extrapolate from surrounding areas into South Vietnam with reasonable confidence. Ground truth for the evaluation of photographic evidence of South Vietnam forests was obtained from accessible areas in neighboring countries - principally Thailand.

2. Based upon ground truth from neighboring countries, an extensive study of aerial photography of Military Region 3 was undertaken. This involved earlier photography produced by the Department of Defense, as well as special sampling flights at low altitudes conducted at the request of the study team and in accordance with its prescribed specifications.*

* Figure 1 shows the location of the photographic sample strips. These flights provided color photography at a 1/5000 scale, making photogrammetric measurements and counts feasible.

3. Information was obtained from the forest product conversion industries of South Vietnam and from similar industrial organizations in neighboring countries to determine a rational basis for setting merchantability standards.

Basis for Study

Forests throughout the world are subjected to occasional and intermittent major structure-modifying events. Such events are commonly referred to as catastrophies or disasters. Frequently they are caused by such natural phenomena as hurricanes, typhoons or other major wind storms; avalanches or earth or mud slides; floods; ice storms; lightning-caused fires or epidemic disease or insect infestations. Sometimes they originate from human activity such as man-caused fires, land-clearing activities or large-scale, exploitive timber harvesting.

Wars have frequently been the causes of such man-caused forest modifications. Forests have historically been the locale for major military actions. When this is the case, the forest is usually one of the victims of the war. There are many ways in which military activities centered in a forest can induce major modifications in the organization, structure and growth potential of the forest. Areas are cleared to improve visibility for personnel security reasons or to provide access and mobility via roads and trails. The troops occupying the forests cut trees to provide fuel and structural materials for housing, as well as for the construction of military installations. Trees are cut to provide camouflage materials and to build and repair bridges. Military forces engaged in a forest war invariably use the forest resource in a very liberal manner. Among all of the major natural resources, trees are perhaps the easiest to convert on the spot to useful products with the tools normally available to troops. They quickly may be converted to military facilities in the form of buildings or fortifications and just as quickly abandoned with the ebb and flow of battle, only to be reproduced on another site with just as profligate use of the forest resource.

Trees are destroyed by bombs and shells used in military actions. And for every tree thus destroyed, hundreds or perhaps thousands more are damaged. Scars resulting from such damage provide sites for infection by tree-destroying fungi and by predatory insects. Imbedded shrapnel degrades the tree and may remain for decades, providing a faulty base for future growth.

The war in South Vietnam is no exception to the general rule. It has been a forest-based war and it has caused great damage to the forests that constituted its principal environment. Kernan (1968) has noted that "the Vietnamese war is probably the most consistently forest war of any recorded, at least in modern history."

One of the new forms of military activity introduced in the war in South Vietnam was the use of massive quantities of various types of herbicide. When herbicides were used as military tools, the intended effect of the spraying was to remove the leaves from the trees, making opposition troops and the trails, their arms caches, etc. visible from the air.

The herbicides used to modify forest vegetative cover were not a military invention any more than are axes and saws. Herbicides have been used by foresters for a long time to control weed species in forests and thus to encourage the growth of desirable species. Herbicides used in forestry induce different responses in different tree species. This differential species response varies from one herbicide formulation to another. In normal forestry use, the practice is to devise an application system which applies a lethal dose to the target species and, at the same time, minimizes the impact of the herbicide on non-target species. Considerable effort has been expended in the conduct of research designed to improve on these herbicide delivery systems. When military organizations adapted the peaceful use of this forest management tool to military purposes, the operation changed materially. The objectives were different, the delivery system was different and the effects were different. In military herbicide use, the principal objective was defoliation to improve visibility. The military advantage of killing a tree, as contrasted with simply defoliating it, was that the operation did not have to be repeated, at least with respect to that particular tree. Since the military need was to affect most large trees regardless of species, the species differentiation characteristic of herbicides was presumably a disadvantage.

Because of the generalized nature of the herbicide target, concentrations of herbicide as used in military operations were much greater than would normally be used in forestry operations to insure effect on the less susceptible species as well as the most susceptible species. Lack of security for operations on the ground dictated the use of aerial application methods except for secure areas along roads and on the perimeters of military installations and secure villages. The aircraft used, fixed-wing airplanes and helicopters, were not susceptible to careful monitoring for effect on target vegetation following each treatment. In a conventional forest-management use of herbicides, such monitoring would be essential. Where excessive damage to non-target species occurred, the treatment would be modified or stopped, since improvement of the forest as a productive enterprise is generally the long-term objective. The military forces using herbicides were engaged in war and not conducting field experiments with silvicultural systems. They appeared to have as little concern for the impact of war on the forests with respect to this military activity as they and their predecessors have historically had with respect to other forest-damaging military activities.

Because the impact of military use of herbicides has been widespread, highly visible, and unknown in terms of residual effects, it has engendered much concern in the United States, South Vietnam, and indeed throughout the world. There has been much speculation concerning the long-term forest effects based on very limited quantitative evidence. This study was initiated for the purpose of evaluating these effects, based on the best evidence available to the investigators. Since it was undertaken while the war was still in progress, direct evidence of the kind that would have been obtainable from detailed study in the forest was not available. It could be argued that efforts to make such an evaluation ought to be delayed until the war was over and detailed field investigations were feasible. There was, however, much merit in attempting an evaluation soon after the cessation of the herbicide treatments. Forests are dynamic systems capable of responding to even the most drastic of system-modifying events. Delay in pursuing investigations could make the ultimate evaluation much more difficult. The final judgment on the impact of this military activity on the forests will have to wait until field investigations can be made by competent investigators.

Damage assessment following the occurrence of a major forest-modifying event is not an unusual forestry activity. It is sometimes undertaken as an effort to assign a monetary value to the damage. This is the case, for example, when fire trespass has occurred. Where forests are viewed as valuable property and where forest ownership is well defined, damage to the property incurred by the owner as a result of fire caused by someone else is sometimes recoverable from the individual, corporation or government agency causing the damage. The monetary value of such damage is usually prescribed and/or circumscribed by the laws of the jurisdiction and courts responsible for enforcing the laws.

The more common case is the task of assessing damage due to a major forest-modifying event in terms of the requirements for change in forest management to minimize the impact of the damage vis-à-vis the productivity of the forest. Under these circumstances, the major effort is directed toward evaluating opportunities for salvage of dead or damaged merchantable material, modification of management plans and treatment of the forest to compensate for unfavorable response to the modifying event.

In the case of the damage assessment associated with the military use of herbicides in South Vietnam, the criteria for measuring the damage are not clear. Accordingly, the forestry study team undertook to examine the modifications in the forest due to herbicide use under four categories: a) loss of mature timber, b) loss of growing stock, c) loss of growth, and d) loss of seed source. The first damage assessment task involved an effort to figuratively reconstruct the inland forest prior to the occurrence of the damage-causing event, to examine its status after the event and to estimate from these two parameters the extent of the change that occurred during the time period involved. The second task involved determining how much of the change observed to have occurred over the elapsed time could properly be assigned to the herbicide treatment. The various forest inventory categories were not equally easy to evaluate. Some could be estimated with considerably more precision than others.

Evaluation of cause and effect relationships between herbicide treatments and forest modification observed is difficult. Prior to, during and following the period of herbicide spraying, the forest areas under study were also subjected to other military actions such as bombing, shelling and land clearing to reduce ambush danger along transportation corridors and to construct roads and trails. In addition, the forests continued to be harvested by both combatants and non-combatants for timber and fuelwood, and cut and burned to provide agricultural clearings (swidden). Even the non-combatant activities such as fuelwood cutting, commercial timber harvesting and cut-and-burn temporary farming were modified by the war in terms of location and intensity. Military activities in a forest area denied loggers access to their normal sources of logs. Restrictions on the use of roads and blockage of the arteries of transportation from forest to mill caused modifications in the usual pattern of wood utilization. Military use of forests interferred with the normal cycle of clear, use and abandon that typifies temporary agriculture. Whole populations of forest-using people were moved out of their normal settings and resettled in areas where their customary forest-related life styles were not feasible. All of these activities and more influenced the changes that occurred in the forests during the period between 1962 and 1971.

The same forests that were treated with herbicides were also subjected to other military impacts. They were frequently bombed and shelled before, during and after the various herbicide events. Since the herbicides were normally used on forests occupied by opposition troops, they were also the forests that were being subjected to the military impact of army harvesting to meet housing, fuel and military tactical needs. These forests were also used between military events for non-combatant logging and temporary agriculture. The many impacts, military and civilian reinforced, compensated for and confounded each other to produce the totality of the change that occurred over time.

Because of this confounding of effects and the problems of security that inhibited detailed on-the-ground study of the forests of South Vietnam, the forestry study team examined the South Vietnamese forests as a geographical sub-division of the Indo-Chinese peninsula. This peninsula lies between India and China and is bounded by the Bay of Bengal on the west and the South China Sea on the east. It is comprised of all or part of several major political sub-divisions. These include North Vietnam, South Vietnam, Cambodia, Laos, Thailand and parts of Malaysia and Burma. The portion of the Indo-China peninsula that is of particular interest is that portion that is the Mekong river basin and the watersheds of smaller rivers draining out of South Vietnam into the South China Sea. Since the forests are not constrained by political boundaries, the major forest types have their counterparts in various political jurisdictions. Because of the paucity of information concerning the forests of the political entity of South Vietnam and because of the inaccessibility of these forests, much information relevant to the defoliation assessment problems can be obtained concerning these forests by studying their counterparts. Williams (1965), after making a study of the forest types of Southeast Asia, indicates that "the vegetation of Thailand, in general, is representative of the countries drained by the Mekong river and its tributaries." Much more research has been conducted on the forests of Thailand and Malaysia than on the forests of the former French colonies on the peninsula. Almost continuous war has prevented forest inventory and growth and yield studies in the peninsula countries since they obtained their independence. Detailed forest inventories have been made of the forests of Thailand (1963) in the Mekong basin. A less well documented inventory was prepared for that portion of Cambodia (1962) that lies east of the Mekong river. In addition, there are forest experiment stations in Thailand where research conducted by the School of Forestry of Kasetsart University and the Royal Forest Service of Thailand have provided valuable information on forest organization, structure and growth far beyond any information on the subject available from South Vietnam. It has been possible also for the forestry study team to extend this information base in Thailand through cooperation with the forest service and the faculty of the Forestry School of Thailand. Figure I-1 is a map of the Indo-China peninsula showing the areas for which inventory information is available and the sites of the special stand structure and growth and yield plots.

With respect to the forests of South Vietnam, the two most important inventory documents available were a soil survey map for the country and a vegetation distribution study and map, Rollet (1962 b). In addition, there was also available to the forestry study team climatic data, Werustedt (1972) for the whole Indo-China peninsula.

Extensive aerial photography was obtained covering the period 1958-1973. Photo interpretation and photogrammetry permitted the development of forest inventory information for South Vietnam for the pre-spray period.

For the purpose of evaluating the effect of herbicide treatment, a detailed study was made of the lowland forests of the eleven provinces comprising Military Region 3. These were the provinces of Bien-Hoa, Binh Duong, Binh Long, Binh Tuy, Gia Dinh, Hua Nghia, Long An, Long Khan, Phuoc Long, Phuoc Tuy and Tay Ninh. Figure I-2 shows the location of these provinces on the map of Indochina. Sixty-two percent of the defoliation missions were directed at this area. Analysis of the herbicide damage to the forests was made using special low-level aerial photographic samples of this area flown for the forestry study team in the winter of 1972-1973. In addition, a

Figure I-1. Map of Indo-China peninsula. Shading indicates areas in which inventory information is available.

Figure I-2   Military Regions of South Vietnam.
The CORPS on the map have been changed to Military Regions (MR).

large quantity of low-level tactical photographs of the area was provided to the forestry team by the Department of Defense. This photo coverage spanned the 1964-1973 time period.

For the purpose of establishing standards of merchantability, the forestry study team investigated the log yards, log landings, sawmills and a plywood plant in Military Region 3 during the winter of 1972-1973. The team was assisted in these studies by faculty from the School of Forestry of the Agricultural University of South Vietnam in Saigon, the University of Florida technical mission in South Vietnam, and the Directorate of Waters and Forests of South Vietnam.

References Cited

(1) Gärtuer, E. J. G. and G. K. Beuschel, 1963.
Forestry Inventory of the Northeast Region (Thailand). Report to the Government of Thailand. FAO No. 1692. Food and Agriculture Organization of the United Nations.

(2) Kernan, H. S., 1968.
Preliminary report (mimeographed) on Forestry in Vietnam. Working paper No. 17, Joint Development Group, Saigon, South Vietnam. 108 pp.

(3) Rollet, B., 1962.
Forest Inventory of the East Mekong (Cambodia). Report to the Government of Cambodia. FAO No. 1500. Food and Agriculture Organization of the United Nations.

(4) Rollet, B., 1962.
Note sur la Végétation du Viet-Nam au Sud du 17 è Parallele Nord. Mimeographed. (Translation by U.S. Defense Mapping Agency, Topographic Center, Washington, D.C., November, 1972).

(5) Werustedt, F. L. 1972.
Climate of South Vietnam

(6) Williams, L., 1965.
Vegetation of Southeast Asia, Studies of Forest Types, 1963-1965. Technical Report, U.S. Department of Agriculture, Agricultural Research Service. 302 pp.

Glossary:

The following glossary indicates the definitions of certain technical forestry terms as these terms are used in the reports on the inland forests.

Area - the area of SVN studied in detail for damage assessment was that portion of the country defined as MR III, Located in the Terrace Region of the country (Section II E[1] and comprised of the provinces of Bien-Hoa, Binh-Duong, Binh-Long, Binh-Tuy, Gia-Dinh, Hua-Nghia, Long-An, Long-Khan, Phuoc-Long, Phuoc-Tuy, and Tay-Ninh (Fig. III B-1).

Damage -Damage is defined as the loss of standing commercial volume as of the winter 1971-1972. Major herbicide operations were terminated in early 1971. It does not include timber killed by herbicide but salvaged between the time of the kill and the time of sampling, nor does it include nonmerchantable timber.

Dbh - Diameter at breast height of a stem equal to 1.5 meters above the ground.

Exploitable merchantable volume - Merchantable timber[a] volume in log form, sealed under the Hoppus rules, acceptable in the South Vietnamese industrial market for manufacture into lumber, veneer and plywood. It does not include timber used directly for fuel, or converted to charcoal for fuel, or used for agricultural and home uses in non-manufactured form.

Forest - Forest is defined as those major areas of land which fall into the following Rollet vegetation types, dense forests, secondary forests, open forests, semi-dense forests. Lone forests were not included.

Inventory Merchantable Volume - The volume based on the inventory merchantable height which is the height from the stump at 1.0 meter to the first limb.

Inventory Total Volume - The volume based on total height of a tree.

Merchantable Volume - Merchantable volume is defined as volume in terms of logs scaled under the Hoppus rule - the customary basis for marketing logs in Southeast Asia.

Non-Merchantable Timber - Non-merchantable timber is defined as the woody vegetation in the forest not utilizable for product manufacture. It includes the non-utilizable stem and crown of merchantable trees, trees of merchantable size but of non-utilized species or of non-usable quality and all trees that are below merchantable size.

Observed Merchantable Mortality Area - Observed merchantable mortality area is defined as an area on the sample that was observed to have merchantable size dead trees.

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[a] In forest products practice, a difference is made between merchantable and commercial timber. For simplification, this difference is not observed in this report and only the term "merchantable" is used.

II. The History of Human Use of the Forests of Indo-China

The original natural forests of Southeast Asia have been modified more or less by human use. The extent of this modification is largely a function of the population density in the region. Areas like Borneo and New Guinea with low population densities have experienced relatively little human forest modification and still have substantial areas of natural forests essentially undisturbed (by humans). The Indo-chinese peninsula is one of the regions of Southeast Asia that has experienced a major impact of human intervention for a long period of time. Williams (1965) notes that a great majority of the inhabitants of the Indo-china peninsula are farmers and peasants and that 85 or 90 percent of the national income of the countries that comprise it is derived from agricultural crops and forest products. The extent of forest modification is a direct function of the population density and its relationship to the size of the forest land base. Among four of the Indo-china countries Laos, Cambodia, South Vietnam and Thailand; Laos has the largest ratio of forest land area to population and South Vietnam the smallest. The ratios of acres of forest land per inhabitant for these countries is approximately 13.23 for Laos, 3.08 for Cambodia, 1.80 for Thailand and 1.44 for South Vietnam. There has been a substantial migration of North Vietnamese and Cambodians into South Vietnam that is difficult to quantify hence the ratio for South Vietnam is even probably lower than indicated by the data.

Many observers of South Vietnam forests have noted the extent of human intervention into the natural forests and the corresponding modifications from the virgin condition. Ralston and Tho (1970) have noted:

> While there is an opportunity for the Republic of Vietnam to expand its wood using industry, it would be a mistake to think that any real competitive advantage exists. True, Vietnam has sizeable but unknown amounts of timber resources which can be exploited to a much greater extent than at present. However on a per capita basis, Vietnam is not in a favored position compared with many nations of the world and Southeast Asia.

Rollet (1962) a French botanist with extensive experience in Indo-china, author of the principal document on the Vegetation of South Vietnam and Director of the FAO

Cambodian inventory project says with respect to the forests of South Vietnam:

> The dense and dense secondary forests of the highlands cover 25,000 km^2 of a total of 45,000 km^2, which is 55%. In the lowlands (below 500 m in altitude), the dense and dense secondary forests occupy 66,800 km^2 of a 123,000 km^2, which is 54%. The amount of deforestation, that is to say, that which has been taken out of the dense forest is nearly the same in the lowlands and in the highlands, 45% if it is granted that originally it must have covered nearly all the peninsula...
>
> It can be said that, in general, permanent farms represent a slim quarter of the country, formations originating from permanent deterioration of dense forests, due to fires and temporary farms, another slim quarter, and the dense and dense secondary forests, a good half of the area of the country....
>
> There probably are very few primitive forests in the lowlands, and it has been noted that the actual dense forests are without doubt aged secondary forests.

Nuttonson (1963) comments with respect to human impact on the forests of French Indo-china as follows:

> ... only a small part of the forests of Indo-china, chiefly in accessible areas, is genuine virgin forest, although much of it is so dense that it gives the appearance of being so. Most of the forests have been exploited by man, who has extracted the most precious varieties from them or else they have been ravished by "ray". This process began long before the advent of the French and has been hastened by urban and industrial development. The secondary forest is much more heterogeneous than the virgin forest. Quick growing types with soft wood predominate, and many of them are without economic value.

The Dwyer Mission (1966) stated with respect to the forests of South Vietnam:

> The largest part of this forest has been pillaged and ravaged for centuries. The mountain people, who needed food more than they needed timber and who had no land to call their own, have slashed and burned the forest to enrich the soil to grow crops of upland rice, potatoes and maize. When in a year or two, the potash was used up or washed off the steep mountainsides, they moved on to clear another patch and then another. This shifting nomadic agriculture has gone on for centuries. Nature moves in behind and restores cover but the trees are transient like the men who abandoned the clearings to them. Usually, these trees are inferior species of low commercial value. Thus, the forest is degraded, and the land and people become more impoverished each time the cycle turns. Perhaps as much as two-thirds of South

> Vietnam's forests have suffered from this process. Today these lands contribute little to the nation's economy - they could contribute much. The forest was further reduced and degraded by an improvident colonial administration. World War II took an additional toll. It is said that 50,000 hectares were devastated by the Japanese occupation. Twenty years of civil strife and war since then has continued to drain off the forest wealth. For example, the settlement of refugees from the North required additional clearing of land for emergency homes and food production.
>
> It is estimated that slightly more than one-third of the current forest land (about 2 million hectares) supports commercial operable timber -- that is, trees of sufficient size, quality, and volume to sustain forest industry. Much of this land supports fine, high quality timber. Under good management, it is capable of supporting a substantial forest industry. But even now, the accessible parts of this land are being high-graded by cutting of the highest quality trees.

Gartner and Beuschel (1963) the directors of the FAO forest inventory project for the northeast region of Thailand state:

> The forests of the North are known to have been exploited for a long period. As the average growing stock in the Northeast is nearly equal to that of Northern forests, it can be assumed that these forests have also been exploited. The statements of the Northeast Development Plan, that "forests are still plentiful" and that regarding the forests under conservation and protection "a large part of said forests has been illegally destroyed" correctly describe the general situation.

Williams (1965) describes the prior use and subsequent status of the forests of Indo-china as follows:

> The primary cause for the presence of a plant association may depend on factors which are active now or have been operative in the past. This is well illustrated in Thailand, as elsewhere in Southeast Asia, where changes have taken place in the distribution of plant life. The destruction of the original growth over large areas, as a result of man's activities during a period of many centuries, has resulted in the modification of the original plant associations, and the development of bamboo brakes and other secondary growth...
>
> The forests of South Vietnam have been devastated for many centuries. Despite ample rainfall and other favorable conditions for growth, the forests were unable to re-establish themselves after prolonged periods of destruction. As a result, much of the so-called forest of what was formerly Cochin-China, now forming South Vietnam, consists in the main of cleared brush land... The forests of the west coast like those of the east, have been intensively exploited from time immemorial, owing to continued and growing demand for fuelwood...

> Cambodia's 33,700 square miles of forests cover approximately 50 percent of the country's total land area,and are entirely in the public domain... The dense forests, or remnants of these, are located in the districts of Stung-Treng, Kratic, Kompong-Thom, Kampot, and Battambang... Stands along the principal rivers have been cut over indiscriminately by the natives. But a few miles from floatable streams there are still almost intact undisturbed stands. In some areas attempts have been made to exploit and develop these stands by opening up roadways....
>
> It is estimated that the forests of Laos cover approximately 62,000 square miles, or equivalent to about two-thirds of the total area of the country.... As in adjoining countries, shifting cultivation accompanied by periodic fires is practiced throughout the years by hill tribes inhabiting the mountains and plateaus. This has resulted in extensive destruction of valuable primary forests. In addition, uncontrolled exploitation of commercial timbers and minor forest products has long been conducted in a wasteful manner.

Kernan (1968) writing for the Joint Development Group notes that:

> Almost every forester who has visited and written about Vietnam has stated that the forests are being seriously overcut and have been for centuries. Typical of these strictures are those of Couffinal (1924) and Cliff (1966). The latter even uses the words "pillage" and "ravage" to describe the clearing of land for agriculture. McKinley (1957) used the word "devastation" to describe the removal of "fine" trees by the Japanese.

Kernan (loc cit) objects to the adjectives used by many to describe the results of human use of the forests of South Vietnam asking with respect to the Japanese exploitation "But in all reason, what other trees would they remove than the ones worth taking out". He suggests that "from a different and not necessarily worse point of view one can use the terms 'land development' and 'selective harvesting' to describe the same activities. Many scientists object to derogatory reference to shifting agriculture on the basis that it is an appropriate land use and the only feasible one in a situation where rural populations must grow their crops on land too infertile to sustain permanent agriculture without massive additions of fertilizer. Whether past use of the forest land is considered to be "good" or "bad" there is little disagreement among competent observers that the forests have been heavily used by man for centuries and that they depart a great deal from the form and structure of the original virgin forest. French colonial forest administration encouraged this type of forest use when it set aside limited areas of forest in parks and reserves and relegated the remainder to non-forest use. During the war that has proceeded almost continuously for the past twenty-five years, there has been little opportunity to protect even the forest reserves and parks. Kernan (loc cit) states that:

> Management plans are inoperative and the distinction has been lost between forest land reserved for permanent production and forest land protected for ultimate conversion to agriculture. The Forestry Administration cannot send anyone into the forest to inspect or supervise logging. Consequently it has no way to distinguish which logs have been cut on areas legally designated for cutting.
>
> This extensively and diversely used forest carried the added burden of providing the environment for a "forest war".

It was portions of this forest that were treated with herbicide. The task of the forestry study team was to determine the pre-spray status of the herbicide impacted portions of the forest. The forests of the Indo-china peninsula have been modified by human use for many hundreds of years. Whether this modification constitutes devastation or reasonable use is a matter of individual opinion but the fact of great change from the original natural stands is well documented. The extent of the modification is a function of population pressure and accessibility. The level of change varies from country to country and from region to region within each country. The forests of South Vietnam have been modified by use more than those of the other four countries. Thailand's forests have been changed somewhat less followed in decreasing order of modification by Cambodia and Laos. The forests of Cambodia are harvested not only for the benefit of the endemic population but also to provide resources for neighboring South Vietnam. Logs from Cambodia are moved down the Mekong River and sold to the sawmills of the Mekong delta in South Vietnam. This trade in logs has continued briskly throughout the period of the war.

It is useful to examine some of the ways in which tropical forests are typically modified through human use. While these are treated as distinct patterns they are in fact examples from a continuum of modifying activities.

The forests prior to war impact derived their character and organization from their original biological structure and the subsequent human use. Typical human modifications are:

1. Selective removal of mature and overmature trees.
2. Removal of all commercial trees above a prescribed size.
3. Removal of the entire forest followed by burning.
4. Burning of understory withoug removal of overstory.

Selective Removal of Mature and Overmature Trees

A form of human exploitation of forest, particularly common in tropical hardwood stands of the sort found in South Vietnam, is the selective harvesting of favored species and sizes. The selection process used in any given situation depends upon a number of factors. If trees are being selected for sale to sawmills or plywood plants, the selection will be for species and sizes that are acceptable to the particular customer being served. Since there is no general log market in South Vietnam, logs are selected for the specific mill market involved. South Vietnam sawmills are often quite limited with respect to the species that they process. One mill will specialize in rosewood and its log yard will contain mostly Dalbergia or Pterocarpus logs. Another mill will process mostly Pahudia or Hopea. The only plywood factory in South Vietnam uses a single kind of wood, Anisoptera. Fuelwood cutters prefer certain species which they select and where they are limited in the tools available for logging they often skip the very large trees with dense wood that are hard to handle with primitive tools.

With reference to the effect upon stand structure of repeated and heavy selection cutting, or more properly high grading, this type of cutting may represent the removal of mature and overmature trees that might be expected to be early candidates for normal mortality. If the number of trees harvested in this way does not greatly exceed the level of mortality in the relevant size classes, and is not highly specific as to kind of wood sought, the impact upon the natural forest organization and structure is not great. If the trees are selected as to species and the selection process is repeated at short time intervals, this form of harvesting can, in the long run, result in depletion of the preferred species in the stand composition. This does not occur rapidly if the species is one that has a relatively high frequency of occurrence in the stand and is well represented in the understory. It would, of course, occur much sooner if the preferred species was one that was relatively low in frequency of occurrence and if the selective harvest extended over a large unbroken area.

Many of the areas of lowland forest in Southeast Asia have, in fact, been high graded over a long period through economic selection in this manner. Over large areas of the lowlands Lagerstroemia has become the most prevalent of the large tree species because it has been less desirable than the Diptocarpaceae species that are far more durable. Lagerstroemia has become a much more prevalent component of the upper canopies of the forest in many areas because of this selection process. In discussing the first class dense forests of Cambodia east of the Mekong River, Rollet (1962) notes that Lagerstroemia represents by far the major proportion of the standing volumes. Gartner and Beuschel (1963) refer to the dominant position of Lagerstroemia in Thailand because of the long history of high grading. They note that while it represents 26.2 percent of the total exploitable stock it represented only 3 percent of the annual cut.

Study of the lowland forests of South Vietnam from low level aerial photographs indicates that Lagerstroemia, a very distinctive tree, represents at least as large a component of these forests as it does of their counterparts in Cambodia and Thailand.

These aerial photographs also indicate that the preponderance of the forests of South Vietnam having large trees in the upper canopies were very low in large tree crown densities prior to the initiation of the herbicide treatment program. This forest structure is a common residual of long term heavy high grading.

Removal of all Commercial Trees above a Prescribed Size

A common method of harvesting tropical hardwood stands of all-aged, multi-species forests in Southeast Asia, where sustained yield forest management is practiced, is to cut all commercial trees above a prescribed minimum diameter with a minimum disturbance to the lowest canopy. Examination of the forest management practices of South Vietnam indicates that this is the basic timber sale practice in that country when the forest service personnel could get into the forests to supervise and control cutting. In some parts of Southeast Asia prescriptions under this harvesting system commonly require that trees above the minimum diameter or girth not removed in logging are killed by girdling or with poisons or herbicides. This is to prevent biasing the species mix of subsequent stands in favor of undesirable species. There is no indication that these forest sanitation practices were observed in South Vietnam when forests were accessible. When this type of harvesting proceeds under conditions that minimize disturbance to the first story of seedlings and saplings or to the soil, experience indicates that the subsequent stand develops in a manner that yields at maturity a forest resembling the original one in structure and organization. Meijer (1970) compared a natural stand in North Borneo with an adjacent stand that had been harvested in this manner forty years prior to the study. He found that where soil and lower story disturbance was light, the stand composition in the harvested area was essentially the same as that of the adjacent natural stand and that the standing volume at forty years was approximately half of that of the unlogged stand. Forest stands that derived from this form of management would have a higher number of specimens in the emergent and main stories than would be the case for high graded stands. Because of the lack of organized forest management in contemporary South

Vietnam, it is difficult to estimate how many hectares of the dense forest reflect this form of prior treatment. Study of low level aerial photography suggests that it is very small compared to the area that has been high graded.

Where removal of the large trees is accompanied by disturbance of the soil and understory, the pattern of succession in the re-establishment of a high forest is somewhat different. Stump sprouts from the original stand provide advance regeneration, bamboo rhizomes provide new culms of bamboo expanding rapidly in the absence of competition and intolerant species such as Trema, Mallotus, Macaranga, etc. invade the area and compete with the bamboo. Lagerstroemia, which occurs as a relatively infrequent tree in the undisturbed mature forest and as a common overstory tree in the high-graded forest, also occurs as a member of the pioneer species group in the forest that appears in early successional stages following abandonment of areas cropped under shifting cultivation. Where fire is a prominent feature of the disturbance and it commonly is in South Vietnam, then the early stages of succession are likely to feature heavy intrusions of high grass and bamboo.

Removal of the Entire Forest Followed by Burning

This is the case where abandonment after cropping is followed by repeated burning--the situation in some higher elevation and drier areas. Here the pioneer species compete with bamboo, imperata, and elephant grasses for occupation of the site. Depending upon soil conditions, these sites recover to the closed forest condition very slowly, indeed. They give the appearance of seas of bamboo or grasses. A study of areas such as this in Thailand that were 6, 12, and 26 years following abandonment (see Appendix 1) indicated that the seedlings of tolerant trees grew under the shade of the bamboo and grass and eventually emerged if fire did not occur. These observations are consistent with reports on succession from other areas of Southeast Asia. Discussing the succession following disturbance of a dipterocarp forest in the Philippines, Brown (1919) states:

> Both cultivated areas and grasslands quickly return to forest if not disturbed by man and fires are excluded . . . when an area is burned over regularly, the grasses form almost pure stands. . . If the grass is not burned, it is quickly invaded by second growth trees.

Burning of Understory without Removal of Overstory

In many areas of the dry-Dipterocarp forests, ground fires occur at frequent intervals maintaining an open park-like appearance. The crowns may or may not close depending upon the stand density. Regeneration is destroyed and the forest has the appearance of a one-storied forest. There is evidence from studies in Thailand that repeated burning is the factor that determines the character of the forest. Exclusion of fire from such stands permits them to gradually recover to multi-storied all-aged stands though the time required for such transition may be a function of the extent of site damage induced by burning. Forests such as this are very common in Vietnam and represent many of the open forest types. Fires induced by military activity added to the normal forest burning and contributed to the maintenance of the dry-dipterocarp forest. Forests of this type have a large fraction of their trees in the exposed canopy.

The extent to which the forest redevelops and the manner of its re-development depends upon the extent of the disturbance. Rollet (1962) reports:

> If a second growth of forest from a dense forest, which has been destroyed by temporary farming is not subjected to the effects of repeated cuttings and burnings at close intervals, the dense forest reconstitutes itself.

Clearly, the impact of military herbicide use in the period 1965-1970 reflected the varied status of the forests involved which, in turn, reflected their prior histories as previously noted.

Inhibited by the absence of a forest inventory and the inability of the inland forest study team to conduct intensive and detailed on-the-ground investigation of the affected forests due to security limitations, the study team adopted the following evaluation strategy for achieving its goal:

1. It was recognized that nature does not observe political boundaries and that the forests of various areas of Indo-china have much in common. Review of the literature of all of these areas provided a much broader information base than would have been possible if the base had been confined to Vietnam.

2. Based upon ground truth from neighboring countries in Indo-china, an extensive study of aerial photography of Military Region III of South Vietnam was undertaken. This involved earlier photographic coverage of the country, military aerial photography made available by the Department of Defense at the request of the study team and in accordance with its prescribed specifications.

3. Simulation models were developed to produce pre-spray inventories of the affected forests. The input data for these computations were derived from inventories of comparable forests in neighboring countries and from pre-spray aerial photography of South Vietnam.

4. Information obtained from the forest product conversion industries of South Vietnam was used to develop appropriate standards of utility and merchantability.

5. Simulation models were developed to analyze herbicide effect under a variety of treatment conditions.

APPENDIX 1

A Study of Succession from Shifting Cultivation to Forest in a Dry Evergreen Forest in Central Thailand

The Inland Forest Study Team was interested in succession from forest removal fon cropping to regenerated forest as part of its concern for the impact of herbicides upon the forest of South Vietnam (SVN). It was known that much of the area of the inland forest impacted by herbicides was secondary forest in some stage of conversion from active ray to older forest. It was apparent from study of the aerial photographs of SVN and from on-the-ground observations of secondary forest treated with herbicide that, whereas these forests contained little or no commercial volume, they were in other ways more severaly damaged than were the older forests. In some instances they were cleared by multiple sprayings almost as completely as were the mangrove forests. In others, many of the seedling, sapling and pole size growing stock was killed. It has been speculated that the extensive use of herbicides encouraged proliferation of non-tree pioneer plants, preventing the establishment of forest tree species. Many of these questions cannot be answered until on-the-ground examination of impacted areas can be undertaken, and even that after more time has passed in some instances.

Since there is little information concerning recovery of inactive swidden under a variety of human impacts and over a substantial period of time, it was felt that a study of forest fallow representing several periods since abandonment might be useful in assessing inland forest damage. Accordingly, Dr. Sabhasri and his colleagues, who served as consultants to the Committee, made a study of several swidden areas in Thailand in areas of dry dipterocarp and dry evergreen forests. While these studies are comparable to only certain areas of SVN, they do provide a basis for interpreting some of the information obtained from photographic evidence related to South Vietnamese secondary forests.

Some of the areas described were the subject of earlier description and evaluation. It was felt that an additional plot measurement would enhance the utility of the earlier data for the purposes of this study.

Introduction

This report is concerned with the study of the trend of changes in species composition on areas abandoned after cultivation in a dry evergreen forest at Sakaerat Experiment Station during December 1972 and August 1973. Though there are numerous abandoned areas with shifting agriculture throughout the country, rarely are they kept under observation. This study, therefore, attempted to visualize the successional stages which have taken place in this forest type.

Locale and Methods

A 20 x 20 meter quadrat was laid down in a dry evergreen forest about the end of 1967 to study plant succession. All plants in this quadrat were removed. The denuded quadrat lies at an altitude of 450 meters above sea level. Soils were derived from sandstone and shales with clay loam texture. The drainage condition was good. The annual rainfall in this forest is lower than in the true rain forest, averaging about 1000 mm per year.

The full description of species composition of the original forest was made by Smitinand et al (1968) and Sabhasri et al. (1968). The common tree species found in this forest type were as follows: *Memcylon* sp., *Hopea ferrea*, *Hydnocarpus illicofolius*, *Walsura trichostemon*, *Aglaia pirifera*, *Canthium brunnescens*, *Syzgium cuminia*, *Linociera microstema*, *Litsea chinensis*, *Lagerstroemia calculata*, *Grewia paniculata*, *Dalium cochnichinensis*, *Ixora* sp., *Melodorum furitiosum*, *Mallotus paniculatus*, and *Phoebe* sp. Tree species were small to medium sized. Only 10 percent of the trees are greater than 22 cm in diameter. In a one-hectare plot there occurs about 55 tree species with 1,140 stems of DBH greater than 5 cm and about 25 species of climbing plants.

The permanent denuded quadrat was observed again in May 1968 and in December 1972, five years after establishment. In addition, observations were also made in two abandoned areas of known ages near the permanent quadrat. These two areas were cleared for cultivation and had been abandoned for 12 and 26 years. The area that had been abandoned for 12 years was located in a dry evergreen forest and about 1 km from dry dipterocarp forest, whereas the 26 year-old abandoned area was about 20 km from a dry dipterocarp forest. It should be noted here that the permanent quadrat was about 3 km from a dry dipterocarp forest.

In order to establish the composition of tree species in the permanent quadrat, as well as in the two abandoned farmlands, 10 x 10 meter quadrats were laid down for enumeration of trees and saplings. To study the composition of seedlings, 2 x 2 meter quadrats were employed and the seedlings were counted.

The following definitions were used in this study: Trees are those plants showing DBH 10 cm and up; Saplings are those plants of heights greater than 1.30 meter and DBH less than 10 cm; Seedlings are plants of height less than 1.30 meters.

Results

In May 1968, one year after denudation of the permanent quadrat, an observation was made to determine the rate of invasion of plant species. Results are shown in Table II-1. It can be seen that seedlings of tree species from the adjacent original forest are now invading this bare area together with those of grasses and climbing and herbaceous plants. These tree species are *Hopea ferrea*, *Nephelum* sp., *Hydnocarpus geddesiamum*, *Melodorum fruitcosum*, and *Dyospuros* sp. Numerous seedlings of *Chrysanthemum* sp., *Eupatorium odoratum*, *Acacia* sp., *Croton* sp., and *Saccharum spontaneum* were found in the first year. The pioneer tree species invaded into the area are those naturally found in dry evergreen forests.

Species Composition in the Permanent Quadrant, 5 Years After Denudation

The impression given by the permanent quadrat five years after denudation was that the area was dominated by E. odoratum. The vegetation was so dense that it was difficult to penetrate. E. odoratum, which appeared to be the dominant species, thrived well with height ranging from 2 to 4 meters. There occurred some amounts of S. spontaneum with average height of about 4.80 meters. Under the continuous canopy of E. odoratum a certain amount of Imperata cylindrica was also found.

Five years after denudation, no tree species have been found to have reached the sapling stage, although some of them had invaded the first year. Throughout the area, however, the climbing plants--e.g., Smilax sp., Cnetis sp., and Anamiraa cocculus--were common. Fern was also present under Eupatorium. Due to the difficulty of working in the plot, four 2 x 2 meter quadrats were laid down randomly and all the seedlings within the quadrats were counted. From the results shown in Table II-2, it can be seen that tree species from the original evergreen forest are still invading, but none have reached the sapling size. Only Eupatorium became a dominant plant in the fifth year, together with some amount of Saccharum scattering among them. From seedling enumeration it is evident that Eupatorium is still regenerating.

Species Composition in the Area That Has Been Abandoned for 12 Years

This piece of forest was cleared for the cultivation of chili, maize, and castor plants. The area was about 18 rais (1 rai - 1600 m^2) in size. The number of years that this area had been under cultivation prior to abandonment was not known.

At the time of observation, Saccharum spontaneum was found to be the dominant species. Several tree species now reached the sapling size with canopies lifted above S. spontaneum. Eupatorium, however, was frequently found throughout the area.

In 1969, i.e., three years ago, two 10 x 10 meter plots were laid down in this abandoned area in order to study the biomass of Saccharum; all plants were removed. During the 1972 observation, these two plots were dominated by Eupatorium. After the complete removal of Saccharum the succession was reversed back to Eupatorium.

Six 10 x 10 meter quadrats were laid down at random throughout the area, and all saplings were measured. To study the composition of seedlings, two 2 x 2 meter quadrats were taken at random and all seedlings were counted. The species represented are shown in Tables II-3 and II-4.

The abandoned areas dominated by S. spontaneum are usually referred to by the local people as Boo. Along the highway between Krabin Buri and this experiment station, Boo is the common scenery. Boo is burned annually in the summer. At the time of observation, fire evidence in the studied Boo could easily be observed through charcoal residues and from burned stems of Saccharum throughout the area. Despite repeated burning, however, tree and species that are naturally common in dry evergreen or both dry dipterocapp and dry evergreen forests have reached the sapling size.

Tree species shown in Table II-3 were those obtained from quadrat sampling. It should be noted here that other tree species were observed to be above the Saccharum, but these were observed outside the enumerated quadrats. These species are Melia azedarach, Lagerstroemia tomentosa, L. calyculata, Nephelum sp., Peltrophorum dasyrachis, Canarium kerrii, and Pterocarpus maccocarpus. Usually these trees species are common among the roadsides. The occurrence of large saplings in this abandoned area indicated that they can grow and compete successfully with grasses even though they are near subject to annual burning. In the area dominated by Imperata grass near the Pakthongchai summer camp, numerous seedlings of P. macrocarpus were also found. The clumps of M. azedarach were common along the newly-constructed highway.

The results from seedling enumeration indicated that tree species from the dry evergreen forest were still invading. Ixora stricta occurred with high frequency. The majority of seedlings found were those of climbers. Numerous seedlings of *Eupatorium* were found under *S. spontaneum*, but this species was not dominant in this area.

Species Composition in the Area that Has Been Abandoned for 26 Years

This area was cleared for cultivation of chili about 26 years ago and was about 1 rai in size. The abandoned area itself is in the dry evergreen forest and the dry dipterocarp forest is about 20 meters away.

S. spontaneum was still dominant, although some tree species had now attained tree and sapling sizes. Four 10 x 10 m quadrants were randomly taken to measure trees and saplings. Within each of these quadrats, two 2 x 2 m quadrats were laid down at random to count seedlings. During the observation, evidence of fire was still present throughout the area.

Morenda coreia, the species common in dry dipterocarp forests, emerged well in this plot together with *P. macrocarpus* and *Mytragyna brunosis*, which are common to both forest types (see Table II-5). The majority of saplings occurring in these plots were the species that have a wide natural distribution, i.e., common to both types (see Table II-6). In considering the seedlings occurring in this plot, it can be seen that a high percentage of the species found are of the primary forest species of a dry evergreen forest.

From the above tables it may be stated that the area now supports the vegetation in an impoverished state. The first successful invaders were species that are distributed widely in both the dry evergreen forests, and the dry dipterocarp forest which is only 20 m away. Although these species usually are resistant to fire, they were almost absent in seedling enumeration. Despite repeated burning in the area (evidenced by the charcoal left during the time of observation), numerous seedlings of primary forest species of dry evergreen forests were still found (see Table II-7). No seedlings of tree species normally of high frequency in dry dipterocarp forests occurred in the area, although 26 years had passed since abandonment. Seedling enumeration may indicate the successional trends are still directed toward dry evergreen forest even though the nearest primary dry dipterocarp is very close to the area.

Discussion and Conclusion

Influx of several plant species had taken place in the first year after the forest land had been cleared. These consisted of primary and secondary forest species, as well as other grasses and herbs. After about five years, *E. odoratum* formed a closed canopy beneath which some seedlings of tree species of the original forest and ferns scattered as a ground layer. At this stage, *S. spontaneum* also formed a secondary dominant species of the area. In 12 years, the area was completely dominated by *S. spontaneum*, beneath which were some tree species reaching the sapling size and some with crowns emerging from the high grass layer. The complete removal of *S. spontaneum* might cause the succession to be reversed back to *E. odoratum*. During the time that *S. spontaneum* became dominant, local people usually set fires every year. Up to this time, a combination of three weed species, i.e., *S. spontaneum*, *E. odoratum*, and *Imperata cylindrica* could be observed. But in the studied areas only *S. spontaneum* or *E. odoratum* were dominant.

The dominant species in the twenty-sixth year was still *S. spontaneum*, and by this time, some tree species had now reached tree size. When the abandoned area was near a dry dipterocarp forest, the first successful invaders were those naturally found in both forest types. In considering the seedling composition, it may be seen that the successional trend, however, is still directed toward dry evergreen forest. The change toward the original dry evergreen forest may be hastened when *Saccharum* disappears from the community; that comes at a time when it is hard to set fire.

Table II-1 Species abundance in seedling enumeration in 20 x 20 m denuded quadrat, one year after removal of original vegetation

Species	Total number of individuals
Eupatorium odoratum (H)	201
Acacia sp. (CL - DEF)	156
Croton sp. (S - DEF)	67
Saccharum spontanum (G)	66
Hopea ferrea (T- DEF)	39
Vitex quinata (T - DEF, DDF)	13
Ixora stricta (S -DEF)	14
Dracaena sp. (S - DEF)	10
Hydnocarpus illicifolius (T - DEF)	8
Erioglossum rubiginosum (T - DEF)	7
Nephelum sp. (T - DEF)	5
Melodosum fruticosum (T - DEF)	5
Paranephelum longifolium (T - DEF)	5
Casearia grewiifolia (T - DEF)	4
Ixora sp. (S - DEF)	4
Flacourtia sp. (S - DEF)	4
Memecylon geddesiamum (T - DEF)	4
Euphorbia antiquorum (T - DEF)	3
Ardisia sp. (S - DEF)	3
Embelia subcoriacea (S - DEF, DDF)	3
Walsura trichostemon (T-DEF)	2

Table II-1 (cont. - 2)

Species	Total number of individuals
Dialium cochinchinensis (T - DEF)	2
Acrocarpus sp. (T - DEF)	2
Chasalia sp. (S - DEF)	2
Clausena excavata (T-DEF)	1
Saprosma latifolium (T - DEF)	1
Diospyros sp. (T - DEF)	1
Phylloclamys sp. (H - DEF)	3
Boesenbergia pandurata (H - DEF)	3
Mitrephora sp. (CL - DEF)	4
Zinbiger zerumbet (H - DEF)	5
Toddalia aculeata (CL - DEF)	25
Willughbeia sp. (CL - DEF)	2
Eleusine indica (G - DEF, DDF)	8
Orthosiphon sp. (G - DEF, DDF)	1
Apluda mutica (G - DEF - DDF)	12
Tiliacora tiandra (CL - DEF)	4
Parameria barbata (CL - DEF)	12
Glossocarya sp. (CL - DEF)	9
Crysanthemum sp. (H - DEF, DDF)	290
Ventilago sp. (Cl - DEF)	14
Neuropeltis racemosa (CL - DEF)	12
Diploclisia glaucescens (CL - DEF)	9

Table II-1 (cont. - 3)

Species	Total number of individuals
Myriopteron sp. (CL - DEF)	17
Goniothalamus marcanii (CL - DEF, DDF)	5

NB

T = Tree

S = Shrub

CL = Climbing plant

G = Grass

H = Herb

DEF = Dry Evergreen Forest

DDF = Dry Dipterocarp Forest

Table II-2 Species abundance in seedling enumeration in the permanent denuded quadrats, 5 years after removal of vegetation (based on four 2 x 2 m quadrats)

Species	Total number of individuals	Frequency
Dracaena sp.*	8	100
Ixora stricta	23	75
Pterospermum sp.	4	75
Ardisia sp.	4	75
Melodorum fruticosum	4	50
Hopea ferrea	2	50
Acacia pennata	2	50
Cnestis sp.*	3	50
Parameria barbata*	2	50
Acacia sp.*	2	50
Ventilago sp.*	2	50
Murrays paniculata	2	50
Croton sp.	5	50
Eupatorium odoratum	abundant	50
Walsura trichostemon	1	25
Diospyros sp.	1	25
Wrightia tomentosa	1	25
Caesalpinia sp.*	1	25
Erioglossum rubiginosum	1	25
Myriopteron sp.*	1	25

Table II-2 (Cont. - p. 2)

Species	Total number of individuals	Frequency
Caesalpinia digyna	1	25
Vernonia elliptica **	1	25
Memecylon geddesianum	1	25
Glossocarya sp.*	1	25
Miliusa sp.	1	25
Neuropeltis racemosa*	1	25

*climbing plants   ** undergrowth

Table II-3 Species from sapling enumeration in the six 10 x 10 m quadrats, 12 years after abandonment

Species	Total number of individual in D.B.H. class (cm)					Frequency
	0-2	2-4	4-6	6-8	8-10	
Acacia sp.*	5	-	-	-	-	50
Siphonodon celastrineus	-	-	-	1	1	33
Gelonium sp.	2	4	-	-	-	33
Cananga latifolia	5	-	-	-	-	33
Capparis sp.	2	2	-	-	-	33
Nephelum sp.	2	-	-	-	-	33
Diospyros spp.	3	1	1	2	-	17
Pterocarpus macrocarpus	-	-	-	1	1	17
Canarium kerii	1	-	1	-	-	17
Melia azedarach	-	-	1	-	-	17
Antidesma sp.	2	-	-	-	-	17
Millettia leucantha	1	1	-	1	-	17
Erioglossum rubiginosum	1	-	-	-	-	17
Grewia paniculata	1	-	-	-	-	17
Mallotus paniculatus	2	-	-	-	-	17
Wrightia tomentosa	1	-	-	-	-	17
Others	1	-	-	-	-	17

*climbing plant

Table II-4 Species abundance in seedling enumeration in the twelve 2 x 2 m quadrats, 12 years after abandonment.

Species	Total number of individual	Frequency
Eupatorium odoratum	abundant	66.6
Tiliacora tiandra*	12	58.1
Ixora stricta	20	50.0
Acacia pennata	5	33.3
Diploclisia glaucescens*	9	33.3
Glossocarya sp.	8	33.3
Bauhinia horsfieldii*	6	25.0
Roureopsis stenopetala	4	25.0
Murraya paniculata	4	25.0
Acacia sp.*	3	25.0
Salacia prinoides	3	25.0
Callophyllum sp.	4	25.0
Ardisia sp.	4	16.7
Dioscorea pierrei*	6	16.7
Congea tomentosa*	3	16.7
Wrightia tomentosa	2	16.7
Walsura trichostemon	3	16.7
Vernonia elliptica	3	16.7
Sterculia sp.	7	16.7
Erioglossum rubiginosum	4	16.7
Memecylon geddesiamum	2	8.3
Albizzia myriophylla	1	8.3
Ventilago sp.*	1	8.3
Nephelum sp.	1	8.3
Chasalia sp.	3	8.3
Phoebe sp.	1	8.3
Grewia paniculata	1	8.3

Table II-4 (Cont. - p. 2)

Species	Total number of individual	Frequency
Cnestis sp.*	2	8.3
Hopea ferrea	1	8.3
Croton sp.	2	8.3
Caesalpinia sp.	1	8.3
Pterospermum sp.*	1	8.3
Caesalpinia sp.*	1	8.3
Trichosanthes bracteata*	1	9.3
Mitrephora sp.*	1	8.3
Mallotus paniculatus	1	8.3
Diospyros sp.	2	8.3
Tinospora tuberculata*	1	8.3
Diospyros sp.	1	8.3
Tiliacora sp.	1	8.3
Phylloclamys sp.	4	8.3
Diospyros sp.	3	8.3
Melodorum fruticosum	3	8.3
Gelonium sp.	3	8.3
Lagerstroemia sp.	1	8.3
Murraya sp.	2	8.3
Irvingia malayana	1	8.3

*climbing plants

Table II-5 Species abundance from tree enumeration in the four 10 x 10 m quadrats, 26 years after abandonment.

Species	DBH classes (cm)			
	10 - 12	12 - 14	14 - 16	16 - 18
Morinda coreia	-	1	-	1
Mytragyna brunosis	1	-	-	-
Pterocarpus macrocarpus	1	-	-	-

Table II-6 Species abundance from sapling enumeration in the four 10 x 10 m quadrats, 26 years after abandonment.

Species	Total number of individual in D.B.H. class (cm)					Frequency
	0-2	2-4	4-6	6-8	8-10	
Wrightia tomentosa	6	3	-	1	-	100
Morinda coreia	1	1	-	-	2	75
Lagerstroemia sp.	5	1	-	-	-	75
Mallotus paniculatus	4	-	-	-	-	50
Lagerstroemia calyculata	1	1	2	-	-	50
Afzelia xylocarpa	-	2	-	-	-	50
Diospyros sp.	1	1	-	-	-	50
Sterculia sp.	2	1	-	-	-	50
Mitragyna brunosis	-	-	1	-	1	25
Salmalia insignis	-	-	-	1	-	25
Dalbergia dongnaiensis	2	-	-	-	-	25
Cassia siamea	1	2	-	-	-	25
Hydnocarpus ilicifolius	3	-	-	-	-	25
Albizzia myriophylla	3	-	-	-	-	25
Capparis sp.	2	-	-	-	-	25
Antidesma sp.	-	2	-	-	-	25
Mallotus sp.	-	1	-	-	-	25
Lagerstroemia tomentosa	-	1	-	-	-	25
Spondias pinnata	-	2	-	-	-	25
Harrisonia perforata	-	2	-	-	-	25
Capparis sp.	1	1	-	-	-	25
Milliusa velutina	1	-	-	-	-	25
Pterocarpus macrocarpus	1	-	-	-	-	25
Cananga latifolia	1	-	-	-	-	25
Dialium cochinchinensis	1	-	-	-	-	25
Diospyros sp.	1	-	-	-	-	25
Gelonium multiflorum	1	-	-	-	-	25
Melodorum fruticosum	1	-	-	-	-	25
Helicteres obtusa	1	-	-	-	-	25
Carissa earandas	1	-	-	-	-	25
Artabotrys siamenisis	1	-	-	-	-	25

Table II-7 Species abundance from seedling enumeration in the eight 2 x 2 m quadrats, 26 years after abandonment

Species	Total number of individual	Frequency
Mitrephora sp.*	18	100
Diploclisia glaucescens*	27	100
Tiliacora tiandra*	7	87.5
Sterculia sp.	13	62.5
Dialium cochinchinensis	7	50.0
Lagerstroemia calyculata	5	50.0
Acacia pennata	11	50.0
Pisonia aculeata	13	50.0
Capparis sepiaria*	4	50.0
Eupatorium odoratum	abundant	50.0
Glossocarya sp.*	4	37.5
Ardisia sp.	3	37.5
Ixora stricta	4	37.5
Parameria barbata*	5	37.5
Vernonia elliptica*	3	37.5
Mallotus paniculatus	3	25.0
Diospyros sp.	2	25.0
Aganosma marginata*	2	25.0
Phylloclamys sp.	2	25.0
Myriopteron sp.*	3	25.0
Saprosma latifolium	3	25.0
Artabotrys siamenisis	3	25.0
Dioscorea sp.*	3	25.0
Coldenia procumbens*	4	25.0
Pterocarpus macrocarpus	3	12.5
Hopea ferrea	1	12.5
Milletia leucantha	1	12.5
Walsura trichostemon	1	12.5
Wrightia tomentosa	1	12.5

Table II-7 (Cont. - p. 2)

Species	Total number of individual	Frequency
Hydnocarpus ilicifolius	1	12.5
Memecylon geddesianum	1	12.5
Caesalpinia sp.*	2	12.5
Bauhinia involucellata*	1	12.5
Dracaena sp.*	3	12.5
Harrisonia perforata*	1	12.5
Tinospora tuberculata*	1	12.5
Roureopsis stenopetala*	1	12.5
Carex indica*	1	12.5
Dolichandrone spathacca	1	12.5
Erioglossum rubiginosum	2	12.5
Antidesma sp.	10	12.5
Murraya paniculata	1	12.5
Xylia kerii	1	12.5
Cnestis sp.*	1	12.5
Helicteres sp.*	1	12.5
Stemona sp.*	2	12.5
Myriopteron extensum*	1	12.5
Caesalpinia digyna	1	12.5
Cananga latifolia	1	12.5
Mallotus sp.	1	12.5
Clausena excavala	1	12.5
Antidesma diandrum	1	12.5

*climbing plants or undergrowth species

References Cited

(1) Brown, William H., 1919.

Vegetation of the Philippine Mountains. Manila, Bureau of Printing, 434 pp.

(2) Cliff, E. P., 1966.

Long Range Forest Policy for South Vietnam. United States Department of Agriculture, Washington, D.C.

(3) Couffinal, M., 1924.

La Situation Actuelle des Forêts de la Cochinchine, Saigon.

(4) Dwyer Mission Executive Report, 1966.

Recommendations for the Development of the Forest Resources of South Vietnam. USAID, Saigon.

(5) Gartuer, E. J. G. and G. K. Bueschel, 1963.

Forestry Inventory of the Northeast Region (Thailand). Report to the Government of Thailand. FAO No. 1692. Food and Agriculture Organization of the United Nations.

(6) Kernan, H. S., 1968.

Preliminary report (mimeographed) on Forestry in Vietnam. Working paper No. 17, Joint Development Group, Saigon, South Vietnam. 108 pp.

(7) McKinley, T. W., 1957.

The Forests of Free Vietnam, A Preliminary Study for Organization, Protection, Policy and Production USOM/Saigon.

(8) Meijer, William, 1970.

Regeneration of Tropical Lowland Forest in Sabah, Malaysia Forty Years After Logging. The Malayan Forester. pp. 204-229.

(9) Nuttonson, M. Y., 1963.

The physical environment and agriculture of Vietnam, Laos, and Cambodia. Mimeographed report, American Institute of Crop Ecology, Washington, D.C.

(10) Rollet, B., 1962.

Forest Inventory of East Mekong (Cambodia). Report to the Government of Cambodia. FAO No. 1500. Food and Agriculture Organization of the United Nations.

(11) Rollet, B., 1962.

Note sur la Vegetaion du Viet-Nam au Sud du 17 è Parallèle Nord. Mimeographed. (Translation by U.S. Defense Mapping Agency, Topographic Center, Washington, D.C., November, 1972).

(12) Ralston, R. A. and D. C. Tho, 1970.

The Forestry Sector of the Economy of the Republic of Vietnam. Mimeographed Report of the USAID mission.

(13) Sabhasri, S., A. Boonnitee, C. Khemnark and S. Aksornkoae, 1968.

Structure and floristic composition of forest vegetation in Sakaerat, Pak Thong Chai, Nakhon Ratchasima 1. Variation of floristic composition along a transect through dry-evergreen and dry-dipterocarp forests. Rep No. 2, Res. Proj. No. 27/1 ASRCT; 20 pp.

(14) Smitinand, T. C., Chaiyanand, A. Nalamphun and T. Santisuk, 1968.

Inventory of vegetation in one hectare (100 x 100 m plot) centered on tower, ASRCT Sakaerat Experiment Station. Rep. No. 3, Res. Proj. No. 27/1 ASRCT; 13 pp.

(15) Williams, L., 1965.

Vegetation of Southeast Asia, Studies of Forest Types, 1963-1965. Technical Report, U.S. Department of Agriculture, Agricultural Research Service. 302 pp.

III. Photogrammetric Utility and Procedures for Damage Assessment

A. Identification of Forest Features from Aerial Photographs

Aerial photographs have been utilized by foresters for many years as an aid in performing inventories of temperate and tropical forests throughout the world. The reader unfamiliar with this art or who wishes to review the development and applications of photogrammetry to forestry is referred to Avery (2) or Spurr (34). Regardless of the type of forest or its geographical location, however, certain common uses of these photos are made.

Photo scale is of great importance in interpretation of aerial photographs. In nearly all tropical studies of this nature the smallest scale used was generally 1:40,000 and the largest scale ranged from 1:10,000 to 1:20,000. The scale used was largely determined by the amount of detail needed and/or the monetary constraints of a given project. The large scale photography gives a great amount of detail but also costs more than the small scale in a comparable type of film. In addition to quality, sufficient overlap of stereoscopic viewing is necessary.

Small-scale photographs, up to 1:50,000 depending on the particular study, are frequently employed to give an overall view of an area under consideration, showing the road network, gross vegetation or forest cover differences, general topography, drainage patterns, or other significant features. This information is essential in the planning stages in determining the logistics of any survey, be it wholly a ground survey or a combined aerial-ground check survey.

The most crucial information provided by the small-scale aerial photos is an estimate of general stand boundaries and variance in and between individual stands. Husch (24), among others, mentions that these small-scale aerial photographs find their main utility in permitting stratification of the forest area. Since practically all inventories are based on some type of sampling, the division of the population into strata depending on variance is a logical step in arranging the sampling plan to be followed. Husch (24) emphasizes the complexity involved at this stage of planning when he states that the sampling design for obtaining measurements requires the integration of information desired from the inventory, the forest, topographic and logistic conditions, and the ingenuity of the designer to prepare a statistically sound sampling scheme which will provide the desired information within the limits of the allowable error and desired probability with the available resources in the required time.

Small-scale aerial photos, combined with existing maps and other information, can give the forest manager an indication of where sample plots can be located and where large-scale photographs might be desirable. The gain in sampling efficiency derived from stratification will insure that only areas especially designated as interest areas will be flown at large-scale, thus avoiding the prohibitive and unnecessary costs of hundreds or thousands of prints over a wide area.

Much has been written on the use of aerial photos during the planning stages of any type of forest inventory, and the preceding remarks did not attempt to analyze this subject in any detail, but only to summarize features common to inventory methods in both temperate and tropical forests. The remainder of this review will be concerned with fundamental differences in the way in which aerial photographs are utilized in these two types of forest inventory.

Before reviewing the methods by which aerial photographs are utilized directly in estimating H (height), B (basal area), or V (volume), and their correlations with ground-derived data, it is advisable to review the procedures traditionally used in forests to estimate these variables, either for the individual tree or for the stand. For the individual tree estimates, plots are chosen with trees tallied by DBH (diameter at breast height = 4.5 ft. or 1.5 M) class, total height, and usually by form class (a measure of the taper of the tree). With this information, the B and the V of individual trees can be determined. With knowledge of the number of trees per unit area, a volume or basal area estimate for the forest can be calculated.

Obviously this is somewhat of an over-simplification -- volume, for example, is generally divided into gross volume (all biomass) and expressed in units such as cubic feet or cubic meters, while merchantable volume measures only the commercially usable parts of the tree and may be expressed in other units. An analysis of merchantable volume estimates derived from ground or aerial surveys would have to consider all the factors which determine merchantability. This is a complex problem which does not lie within the scope of this review.

Yet the important feature to be noted is the approach: it is necessary to measure and tally each tree in the sample plots so that, after the required computations, an estimate for the B or V per DBH class per unit area can be made. Estimation of B or V on a per acre or per hectare basis is a matter of simple multiplication, (Estimate of plot B or V)×("Blow-up" factor to convert to per acre [hectare] basis). Estimates for the entire inventory area subsequently are found by multiplying by the total acreage. This method of making measurements on each individual plot tree, which is typical of temperate forest mensuration, is to be contrasted with another method in which few individual tree measurements are made, with the plot or population estimates derived from linear regressions. However, this second method, common for tropical forests, will be discussed later.

While the forester on the ground has information as to DBH, tree heights, and tree form, the forester using aerial photos can measure directly only the second. The parameters available with photographic image analysis are individual tree heights and individual crown widths or areas. Since direct DBH estimates are not possible, some other parameter or parameters must be substituted.

It is important to point out that recognition of individual sample trees is essential with this approach. This fact has three important implications:

1. The scale of the photographs must be sufficiently large so that individual crowns can be delineated. In many studies it was found that 1:5000 was acceptable, but the scale could be larger depending on the local conditions.

2. The species of the individual tree must be identifiable. In many cases the forest has a limited distribution of species, so that the particular species can be determined on the basis of texture, tone, shape, height, or other characteristics of the photo image. Certain species have unusually formed crowns and these are often readily recognized. In addition, multi-spectral imagery may assist the photo interpreter to correctly identify species not readily identifiable with a single image.

3. Since the total tree height is determined using the stereopair, either with a stereometer or a sophisticated plotter, it is necessary to be able to see the ground at the base of the tree as well as the top of the tree.

While implications #2 and #3 above might seem obvious, it is this combination of factors that makes tropical forest inventory much different from that of temperate forests. The number of species over four inches in diameter, according to Richards (31), is seldom less than 40 per hectare and sometimes over 100 species. In addition, many tropical forests have more than one canopy so the ground and trees in the lower canopies may not be visible. The argument that canopy layering is a feature unique to tropical forests thereby precluding use of photogrammetric techniques used in temperate forests is not valid since in many areas temperate forests also exhibit this phenomenon and aerial photo techniques have been used in them. The principal point is that the methods used in temperate forests may be more difficult to use in tropical forests particularly in tropical stands that are dense with multiple canopies and many species.

Nearly all the studies of aerial photography in the tropics agree on its utility in classifying forest types. Some of the methods of delineation are covered by Nyyssonen (28): "In addition to species composition, the classification may take into account, for example, the density and height of the stand, crown size and appearance, local topography, moisture and soils, as well as human influence (exploitation, shifting agriculture, etc.)." He notes that several types which can be singled out in Indonesia are plantations, grass areas, logged forest, and secondary forest (old and young); natural vegetation can be recognized as dryland forest, marshland forest, and mangrove forest. Variations of schemes are found in other areas but most publications defining the forest types are concerned with Southeast Asia. The detail or breakdown of information is largely dependent upon the photo scale. He adds that some types, in Thailand and Ceylon appear to merge together with indistinct boundaries, and thus necessitate ground supplements. A survey of literature pertaining to Southeast Asia plus observations (38) indicate that forest types, subtypes, and sometimes individual species can be distinguished. The most difficult identifications occur in dense Evergreen or moist forests where extensive areas look practically homogeneous. Principal characteristics that can be evaluated are tree height, crown diameter, and crown coverage. In dry and open forests additional information may be obtained.

> "The information obtained from aerial photographs is either directly visible from them or can be assessed indirectly. The sum of the factors of the environment that influence tree growth is measurable on aerial photographs, to the extent that key factors of the environment can also be recognized." (38)

According to Loetsch and Haller (26), more than 10,000 tropical tree species have been described worldwide, with pure stands far and few between. They state that "the commercial and utilization value of the tree species in the tropical primary forest differs widely. An estimate of the total standing volume, perhaps above a minimum diameter, is therefore of little value and the distinction of tree species essential. This separation of species growing stock assessment is even necessary for the pulpwood volume because of the complete mixed pulping of tropical hardwoods is still uneconomic." Furthermore, the crown habit or vertical projection of the crown shape changes with age for most species.

Individual species have certain characteristics and often these are discernible from the air at a reasonable altitude. For example, tall trees such as certain species of Dipterocarpus or Lagerstroemia have straight light colored trunks which stand out conspicuously even when surrounded by a carpet of foliage in the moist dense forest. Fig trees (Ficus) normally have a widespreading umbrella-like crown, and corpulent branches. Teak

(Tectona grandis) can be readily spotted when in flower, or in the dry period (38).

It seems that many species may be identifiable because of certain unique seasonal characteristics such as flowering or leaf shedding. Past species identification studies may perhaps be biassed by the season in which the photos were taken as well as the photo scale. These factors may play an important part in the conclusions reached by the following authors.

Swellengrebel (37) found identification to be a problem in British Guiana where trees with old leaves had a dark appearance on the photography whereas trees with new leaves showed up as light tones. Trees protruding from the general canopy had a lighter crown than others of the same species. Some species in groups could be identified by stand features but this seldom occurs in the tropics. Heinsdijk (8) suggests crown form as an indicator rather than tonal differences on the photo.

Nyyssonen (28) reports that during the 1950's, studies in the Malili forest (photo scale of 1:10,000) of the Celebes (Sulawesi) and in Sumatra (photo scale of 1:40,000) gave negative results in general--encouragement only in exceptional cases.

Locating parana pine in the Amazon region mixed with tropical broadleaf was quite difficult according to Heinsdijk (20), however he noted

> "...The possibilities of seeing more of the smaller parana pine trees on the aerial photographs by changing the scale from 1:25,000 to 1:10,000 or even to 1:5,000 are practically unlimited."

Spurr (34) states that all photo-interpretation, whether in the field or in the office, should be done with the aid of a stereoscope. In addition, many other devices (i.e., photogrammetric instruments) may be utilized. The most important objects to recognize on the photographs are shape, dimension, tone, texture, location, shadow, and association. Considering always their photographic qualities, the interpretation of aerial photographs should be done methodically and proceed from the general to the specific items. The skill of the interpreter is most important as are extensive training and field experience.

> "Geological photo-interpretation must be done by the geologist; soils interpretation by the soil scientist; and forest photo-interpretation by the forester."

Characteristics such as tree height, crown coverage, tree tallies, crown diameter, and scale must be considered in volume estimation. Bole diameter is also used, but must be obtained from ground measurements or indirectly from measureable photo features and previously established relationships.

Tree height can be obtained by various means which are outlined by Loetsch and Haller (26).:

1) Measurement of shadow length
2) Measurement of parallax differences
3) Ocular estimation

It has often been found difficult to measure tree height from aerial photos particularly when confronted with a dense canopy and/or dense undergrowth. According to Nyyssonen (28) tree height is not characteristically measured in tropical aerial surveys due to low correlation between top-height and bole diameter. He further states that the length of the clear bole is generally better than tree height.

Swellengrebel (37) has found that use of crown coverage is limited since its measurement assumes incomplete closure which seldom occurs in dense tropical or multiple layered forests.

Loetsch and Haller (26) indicate that tree counts are generally underestimated and that large-scale photography is desirable for more accurate counting. Swellengrebel (37) found that in "mixed forest" with a height-range of 70 ft. - 170 ft., crowns of large trees were bigger and often overlapped trees in the 12 in. and 16 in. DBH (diameter breast high) classes. Spurr (34) indicates difficulties in using both crown closure and tree counts as measures of stand density because of the problem of separating tree clumps into distinct component stems. These clumps may be tallied as a single stem. A single stem exhibiting a forked trunk or pronounced large branches may be counted as several stems. The net bias depends on the skill of the observer, scale of the photographs, and vegetation density. Ferree (15) feels that the beginner tends to undercount. Nyyssonen contends that these problems are worse in tropical forests and concludes that tallies are of little value as density indicators in the tropics (28).

Crown diameter is one of the most useful features measureable from aerial photographs. Loetsch and Haller (26) recommend that crowns far removed from the photo center be measured at a right angle to the radius from the principal point to reduce the displacement effect and at a right angle to shadows. Crown diameter measurement should be taken from the photo having the particular tree closest to its principal point. They contend that generally the bias of the interpreter is more important than the measuring device. Ferree (15) stresses that the tree crown be measured stereoscopically rather than how it might ocularly appear on one photo. The tendency with ocular estimation is to overestimate crown size which will lead to overestimation of volume. Stereo eliminates measuring these displaced images which are always larger than true size. Furthermore, inexperienced observer error in assuming a clump of small trees as one large crown or vice versa can strongly influence diameter and volume predictions.

Paijmans (29) showed that separate visible crowns generally belong to trees which are marketable and Nyyssonen (28) suggests that tree crowns which are not visible probably play a minor role in merchantability. The implication is that if a study is principally interested in merchantable volumes then merchantable trees should be the most easily observed components of the forest structure and thus be subject to the least error in crown diameter measurement and stem count.

Swellengrebel (37) believes the value of volume to be dependent upon the validity of the regression of crown diameter and DBH. A linear relationship would imply that an increase in DBH corresponds to a proportionate increase in crown diameter. He states that this is not always true: an overmature tree often forms a "compound crown" which loses big limbs later and thus reduces c.d. which may lead to one measuring small instead of large; a small tree growing without suppression can develop a large crown and consequently be tallied as a large tree. The relationship between c.d. and DBH is obtained from ground measurements of each factor.

B. Comparison of use of Photogrammetric Forest Inventory Procedures in Temperate and Tropical Forests.

The common feature of most studies to date in the temperate forests is the search for correlation between photo-obtained data and ground-obtained data. It is essential to recognize at the outset that photo-derived and ground-derived measurements will always have error, and it is necessary to know how great these errors are in order to determine precision of estimates. When comparing the different sources of data, there is a strong temptation to consider the ground data as "true," when it in fact is also subject to various errors.

In his experiments, Bonnor (3) collected individual tree data (stem diameter, tree height, crown width and crown class) and stand information (site class and canopy density). He performed a multiple regression analysis for red pine (*Pinus resinosa* Ait.), finding that tree height and crown width gave the best estimates of stem diameter, with the equation:

$$D = a + b_1H + b_2W + b_3HW,$$

where D = stem diameter at breast height
H = total tree height
W = crown width

Bonnor continued his investigation with four additional softwood and five hardwood species, deriving a high correlation for each (lowest was for jack pine[*Pinus banksiana* Lamb.], with r = 0.896). He also attempted to combine several species together, but no compromise equations of reliable correlation could be established. Standard errors for the softwoods ranged from 17-19% of mean diameter, and from 18-26% of mean diameter for the hardwoods. A more detailed survey of DBH-crown diameter lleterature in section IVC indicates that other researchers have found useful relationships without including height as a variable. Furthermore other studies have obtained strong correlations even when species were combined. Bonnor utilized tree volume equations developed by Honer (22) in 1966 to make volume estimates based on the photo-measured heights, but found that the standard errors of the diameter and the volume estimates were too high to produce reliable single-tree estimates. His conclusion, however, is noteworthy: The equations should be sufficiently accurate for the determination of acceptable volume estimates of sample plots and stands, which is the primary purpose of most forest inventories.

Sayn-Wittgenstein and Aldred (33) of the Forest Management Institute in Canada have also been engaged in research relating to determination of volume and basal area using large-scale aerial photographs. Their first studies in 1967 found that in typical mixed coniferous and hardwood stands about 85% of the trees could be identified correctly, that heights of trees could be determined with a standard error of estimate of about 3.5 ft., that crown diameters for regular-crowned trees could be measured with an accuracy of 2 ft., and missing no more than 4% of the trees on a sample, representing a volume loss of only 1.5% because most omitted trees were small. One significant difference from the work of Bonnor was that "it should be emphasized that one is interested in estimating volume and not tree diameter." Sayn-Wittgenstein and Aldred concluded that it is more accurate to relate tree volume directly to photo-measured variables.

Concerning regression, these researchers found that an equation based only on (H*log CA) and NH gave a good solution for all species groups, where H = tree height, CA = crown area, and NH = number of trees growing in a circular area surrounding the tree under consideration, with the radius of this circle equal to the height of that tree.

Continued work on this subject brought another report in 1972 by the same authors (1). Using 1:1000 photographs, it was found that the independent variables that proved most successful as estimators of volume were also the best for the diameter-estimating equation. The most useful equation was:

$$\hat{Y} = a + b(H) + c\,[H\sqrt{(CA)}] + d\,[\sqrt{(CA)}]$$

where $\hat{Y}$ = estimated tree diameter (or volume)
H = tree height
CA = crown area
a,b,c,d = least-squares regression coefficients

Referring to their conclusions in 1967, the authors found that there was little further evidence that the measures of relations to neighboring trees were useful, although they did occasionally emerge as significant variables. Another important observation is that crown area was found to be a more reliably measured and more useful variable than crown radius or crown diameter. However, because of a complete lack of standardization of crown measurement from aerial photographs, comparison of results from different authors is most difficult.

Stellingwerf (35) is another who has examined the accuracy of photo-derived measurement of trees. He states that the visible tree height in a stereoscopic model differs from the actual tree height for the following reasons: difference in contrast between crown and background, contrast within the crown, dimension and shape of crown, reflection angle, amount of light, and personal appreciation of height. He found that random error in measured tree heights consisted of

1. the error in setting the floating mark on the visible tree top,

2. the error in the setting of the floating mark on the terrain, and

3. an error due to varying discrepancies between actual and visual tree heights.

Repeated measurements can reduce error due to 1 and 2, but the variation in the systematic variation (the mean of the discrepancies of the 20 samples, with discrepancy = actual height - measured height) remains the greatest error. Trials were made at two scales (1:10,000 and 1:20,000) and with different photogrammetric equipment (Wild A8 and Santoni Stereomicrometer) for height measurement in sample plots but it was found that the influence of the operator may outweigh others such as scale and instrument.

An interesting conclusion that Stellingwerf states is that

> ....estimations of tree heights can replace measurements. The estimating method is about fifteen times quicker than measuring the dominant heights of plots with the parallax method in instruments in which the stereomodel must be oriented. The use of these instruments is necessary in closed forests for avoiding errors due to model deformation. In open forests where the ground in or near the plot is visible, measurements can be made with a parallax bar under a mirror stereoscope or with a wedge under a pocket stereoscope. The gain in time compared with the latter instruments is less obvious of course. Each method involves errors, both systematic and random. These errors have to be controlled.

He then proceeds to explain how a double sampling system can be used to control errors. A regression between estimated height on the photos and the measured ones on the terrain in double-plots was used, and it was discovered that for both 1:10,000 and 1:20,000 that the correlation coefficients were fairly high (r=0.87 and 0.82 respectively). The adjusted estimated mean height and its standard deviation was for the scale 1:10,000: 19.1 ± 0.5m, or for P = 0.05 the standard deviation was ±1m or ±5%. For the scale 1:20,000 the adjusted estimated mean height and its standard deviation were: 19.0 ± 0.24, or for P = 0.05 ±0.5m or ± 2.5%. The terrestrial measurements is situated within the 5% confidence limits of the means, which are obtained from the estimations.

Stellingwerf's suggestion that perhaps only height estimates be made under some conditions returns again to the basic dilemma of the forester/photogrammetrist, who must opt either for slightly more accurate results (using stereoscopic plotters), or accept less accurate information using estimators (such as stereometers), with the advantage of considerable more speed and possibly lower costs. If volume estimates are to be made with tree height data, in which three different factors (basal area, height, form factor) are eventually combined to provide an estimate, then each input carries its own standard error. Consequently the photogrammetrically-derived measurement would be preferable. On the other hand, if the volume estimate were made on the basis of an average stand height, then the estimated heights might be sufficient.

Gerrard (16) in 1969 examined error propagation models in estimating tree size and made a number of interesting observations. He pointed out that many previous studies matching photo-derived estimates with ground-measurements failed to analyze the error in the ground procedure, simply taking the latter as the "true" data. It might be suggested that with repeated measurements of the tree from the ground(as in Stellingwerf's study) that the random error would be negligible, leaving only supposedly

the base of the tree might be. However, if the forest is open or has been extensively exploited, the ground is usually more visible so that techniques standard in temperate areas may be used. This certainly is the case in South Vietnam where much of the Inland Forest has been extensively exploited.

From the photogrammetrist's point of view, the dense multiple layered tropical forest poses difficulty in the relative and absolute orientation procedures of the stereoscopic model. This problem arises from the impossibility in many areas of placing the floating dot on the ground or some "hard," well-defined point; if placed on top of vegetation, it is much more time-consuming and less accurate to remove the parallaxes at the five or six points used in the orientation process. Obviously it is necessary to have sufficient vertical ground control points so that the model can be leveled during absolute orientation. However, in most parts of the tropics this information is not available, and the cost of setting a large number of vertical (and horizontal) control points could be prohibitive if the inventory area is large.

The inability to accurately distinguish species from aerial photographs in tropical forests is another characteristic feature. Many species, especially those which occupy the lower canopies of denser stands, can simply not be seen in the photograph for they are blocked out by trees in the taller canopies. Those trees which are in the emergent canopy are frequently the only ones which can be identified by species, and in an area of high floristic complexity even that might not be possible. This may not be a critical feature in more open or exploited forests or if one is principally interested in trees of commercial size and species which would be found more frequently in the upper canopy and therefore would be more easily identified. Also where field sampling allows estimation of the proportion of species that are the nonmerchantable stand component, this proportion can be used to adjust volume figures.

Of course some trees in the tropical forest are measurable by the techniques analyzed before, but often there is not a sufficient number of these to consider them as samples from which estimates can be made. The basic implication is that stand height, basal area, or volume estimates cannot be derived from individual tree data in dense tropical forests, but must be developed in another way.

In 1971 Stellingwerf (36), observed that in tropical forests the correlation between photo variables and field measurements has been investigated only in a small number of cases but, so far as is understood, no actual use in practice has been made of such studies.

In the same year, Holdridge et.al. (21) published the results of a pilot study concerning forest environments in tropical life zones. Their basic approach was to correlate field data with photo-derived measurements for various parameters. These will be analyzed individually.

Holdridge's group found that the only areas in which tree height estimates were possible using the aerial photographs were in the Tropical Dry and Moist Forest Life Zones, where the ground was visible in several places. Panchromatic (PAN) and infrared (IR) generally gave better results for these measurements than false-color or camouflage detection infrared (CD) or color (EA). An effort was made to correlate crown area with individual tree height but less than 60% of the variation in crown could be attributed to tree height. The authors suggested that even if the vegetation is dense and an opening is not available within the site, every effort should be made to locate "comparable" vegetation near the site where measurements of height can be obtained, such as along trails, rivers, blowdowns, and other man-made or natural openings.

As part of the ground control for this study, ground contour maps at the scale of 1:1000 had been made. The primary purpose of these was to establish the base from which vegetation height was determined in the airphoto study. For each site approximately one hectare was contoured at 5 ft. (1.5 M) intervals relative to an arbitrary zero counter, linked to the datum for the site. In addition, 23 canopy contour maps were constructed from aerial photos, in which discernible tree crowns were outlined and peak elevations given for each. For these also a contour interval of 5 ft. (1.5 M) was used and various types of crown cover were coded. The majority of these maps were made from IR photographs using a Kelsh plotter. For all sites (most representing distinct Life Zones) the average photo stand height and the average field stand heights showed a strong correlation, with r = 0.922, the airphoto stand heights being generally lower.

For estimates of stand basal area, the normal procedure of tallying tree diameters could not be followed, because DBH is not a photo-measureable parameter. Hence three different approaches were attempted.

The first method attempted to correlate basal area with crown area, on the basis of cross-identifiable trees. The second method, correlation of the tree height with basal area, was tried in those areas where it was not possible to associate crown images on the photographs reliably with the corresponding trees in the field data. When these two methods were combined, the correlation of field basal area and photo-derived basal area was not especially good (r = 0.482).

The third approach was to estimate stand basal area by correlation of total basal area with total crown area without resorting to correlations based on individual trees. The authors found this procedure faster, simpler, and more conveniently applied to situations in which direct field measurements were not possible. The gross crown area per 0.1 ha was obtained from the sum of the areas of distinctly delineated crowns in the sample area. The correlation coefficient was somewhat higher, $r = 0.658$. The authors suggested that these correlations should be re-examined with additional data to increase their statistical reliability.

The study also comprised an analysis of stand density as measured from aerial photographs, in which the number of stems per unit area was observed. Similar to this was an estimate of species density, in which the number of species appearing on each film was noted with no attempt at actual species identification. This was done by making a relative count of different combinations of tone and texture, and, to some extent, shape. The correlation between field stand density and photo-measured stand density was not particularly good ($r = 0.518$). For the species density, it was determined that wetter climates were more complex and variable, had more species present, and in them relatively smaller percentages of the species present reached into the upper canopy where they could be seen. Hence the correlation between photo species density and field species density was only fair, $r = 0.310$. Identification of but a few species was possible because of the highly mixed floristic composition of the forest. In general it was found that the accuracy for photo tree heights was $\pm$ 1.5 m and for crown widths was $\pm$ 3.0 m for 1:10,000 photography using a plotter.

It is significant to note that Holdridge's study did not attempt to make any estimates of the volume, either gross or merchantable. Though stand basal area in temperate forests is often used as an indicator of stocking percent, which in turn can combine with other factors to determine a volume estimate, it is of dubious value in the tropical forest inventory. Because of the heterogeneous structure of this type of forest, virtually all of the area will be covered by some type of woody vegetation, either shrubs or trees. The timber inventory seeks to determine how the volume is distributed among the trees, but this information is not inherent in the basal area figure. A plot with 1200 small trees could have the same basal area/hectare as one with 500 large trees, the latter having greater basal area/tree (greater diameter/tree) and, in most cases, more merchantable volume.

Detailed estimation of inventory volume present in dense tropical forests by methods other than ground survey does not seem a strong possibility, at least at the present time. Boon (4) wrote a critical review of timber survey methods in a tropical rainforest, but his observations and conclusions were based on terrestrial work alone. He noted that particularly in tropical rainforests, which have very mixed species composition and are not readily accessible, a preceding study of available photographic material, sometimes combined with ocular observations from a low flying plane, has proven to be essential as a basis for the overall planning of the terrestrial survey. But he adds that the remaining part of the survey -- both at present and in the near future -- is predominantly terrestrial. This is due to the fact that special methods which have proven to give practical results in timber volume evaluation for temperate forests usually fail in the tropical rainforest, mainly because of the heterogeneous species mixture.

In his study, Boon mentions several factors which make it extremely difficult to estimate tropical forest volume. For even an estimate of the biomass present (in terms of cubic feet or cubic meters of all trees or shrubs = gross volume, or of only all living trees or shrubs = net volume) it is necessary to have extensive information on tree taper or form. If this information is not available for each species, an average form factor for the stand might be acceptable, especially if it reflects the trees which have larger volumes.

If merchantable volume is to be considered, the problem is compounded significantly. Merchantability depends on many factors, economic, such as accessibility to mill, market supply and demand, ownership, etc., and biological, such as species, size, ring characteristics, fiber characteristics, shearing strength, percentage of internal rot, external defects, bark thickness, etc. In most cases none of these biological factors, except size and occasionally species, can be determined using aerial photographs. In contrast, species and size are readily identifiable in most temperate forests. Furthermore, in many temperate areas, a great percentage of the old-age growth has been removed and younger "second-growth" stands are present, which generally have little rot or defect.

Heinsdijk (19) considered crowns emerging above the level of forest canopy (greater than 25 m height) of forests in Surinam as the upper story. He found a close relationship between crown width of upper story trees and their respective DBH's such that the volume of the upper story trees usually indicated the total volume of growing stock. From findings of other workers plus observations of his own, Nyyssonen (28) concludes that

> "...if the volume of all the trees above a certain size limit can be studied from aerial photographs, some indication can be obtained at the same time of the structure of the growing stock and at least of the amount of commercial wood."

However, he feels that there are limits to the application of this estimate without knowing the stem defects, identification of commercial tree species, etc.

Swellengrebel (37) made the following conclusions as to the constraints on volume estimates:

1) Without good tree species identification volume figures are accurate only by vegetation type.
2) Assuming a toleration of 70% visibility, the minimum DBH is 20 in. for vegetation types with thick and irregular canopies and 12 in. for a vegetation type with thin and regular canopy.

Since the relationship between stem and crown diameter, which may be used to translate photo-measured crown diameters, to estimates of DBH from which volume can be obtained, it is useful only for crowns that may be observed in the photo. Therefore, the volume of merchantable trees in the understory may be underestimated, particularly in dense, layered stands. Dr. de Rosayro (10, 11) contends that the combination of crown measurements and tree tallies from aerial photographs provide only a "very rough estimate" of volume for tropical forests. He bases this belief on studies such as that conducted by Hannibal (17), a preparation for forest inventory of Indonesia. It should be noted that this criticism is valid mainly for total inventory volumes. Merchantable inventory includes exclusion of most understory trees which are too small for utilization. Thus merchantable inventory deals with the larger trees which usually are found in the upper portions of the canopy and thus easily observed, measured, and counted in a photo of reasonable scale.

It is expected that more studies similar to those carried out by Holdridge's group will attempt to alleviate some of the problems of tropical forest inventory using regression techniques, based on the photo-measurable parameters of tree (or stand) height, crown width or area, and species (or stand) density. Perhaps volume estimates can eventually be made almost entirely on the basis of aerial photographs within the limits of the specified allowable error. The fairly large error inherent in most ground surveys, especially in tropical regions, might suggest that regression analyses could lead to estimates of similar accuracy in the future.

It is clear from this survey that a reasonable damage assessment and inventory for South Vietnam may be carried out if

1) The forest area is stratified into meaningful forest types.
2) Attention is restricted to merchantable size trees. Since these tend to be larger specimens, they will be found on the upper levels of the forest canopy where counting and crown size class segregation can proceed rapidly and with little error.

3) If a suitable relationship between crown diameter and DBH can be developed. This will allow translation of counts of merchantable size trees by crown size class to counts by DBH class. Derivation of such a relationship is discussed in the next section.

4) If currently utilizeable volume per tree for each DBH class can be defined. This is best obtained by surveys of logging operations and mill yards where the material actually taken from a tree can be easily measured.

5) With estimates of taper from log measurements, estimates of height obtainable from inventory plots of stands of similar composition in neighboring countries, and live and dead tree counts, a preliminary forest inventory may be calculated.

C. Stem Diameter/Crown Diameter Relationship

Determination of inventories and assessment of damage require a procedure for estimating timber volume. Since ground measurement was impractical at the time of study, the analysis relied on the use of extensive aerial photography in conjunction with photogrammetric methods to classify the forest area into forest types and to observe the numbers and sizes of dead and live trees. Volume estimation requires a means by which the stem diameter at breast height can be estimated from the aerial photographs. Since tree trunks often cannot be directly observed in aerial photographs, the desired result must be based on a relationship between stem diameter and some measurable observable characteristic. One characteristic of forests that is plainly visible on aerial photographs is the canopy surface, and the crown diameter of the individual trees is a practical feature that is readily measurable.

A procedure which may be used, is to develop a relationship between stem diameter and crown diameter by field sampling randomly selected trees, establishing the predicting equation, and using the equation in conjunction with individual tree crown measurements from the photographs to predict tree stem diameter. Any of a variety of volume relationships based on stem diameter may then be used to estimate volume.

The existence of a consistent stem diameter-crown diameter relationship has been established in many regions of the world (3, 14, 23, 26, 30, 34). While the actual relationship developed varies among authors due to differences in sampling and analytical techniques, the form is generally consistent. In a tree, the developmental and physiological constraints requiring it to develop a structural balance between the various organs to withstand the forces tending to overturn it would suggest the occurrence of such a relationship. A tree with a large heavy crown would be expected to develop a larger supporting system than a tree with a smaller lighter crown.

In order to develop a stem diameter-crown diameter relationship model and to make predictions with it certain assumptions must be made about the population of interest. The assumptions made for development of such a model for the Inland Forest of South Vietnam are:

1. Tree height, density, site and age do not affect the form of the model.
2. The model can be developed and used for multi-specific sites.
3. Data from tropical forests of the same or similar types from neighboring countries are applicable to South Vietnam.

The assumption that a useful relationship can be developed without including age, height, site, and stand density is based on evidence from other studies. Bonnor (3), in studies of six coniferous and five deciduous Canadian species considered the effects of site, canopy density, tree crown class and height and found that only height had any appreciable effect in improving the relationship. Spurr (34) notes that although good estimates of stem diameter can be obtained from crown diameter alone, the estimate is improved when height is added as an independent variable. Curtin (6) found that the crown-stem diameter relation for Eucalyptus obliqua was unaffected by other factors for open grown trees but that height is an additional factor for dense more intensely competing trees. In a later study (7), he demonstrated that stand density also has an influence. It should be pointed out, however, that he was able to obtain a useful prediction equation without the factors of density and height. Kwan (25) found that the crown-stem diameter relationship of Dyera costulata from two localities in Malaya representing widely different environments were not significantly different. Dawkins (9), in a study of African species, noted that subordinate trees sometimes showed little correlation in a natural forest but that unsuppressed trees do. He also found that height was generally not a significant factor in his data. On the basis of the literature it seems safe to assume that site and age do not influence the stem-crown diameter relationship. Evidence concerning height and density is conflicting, in some cases these have been found to improve the relationship while in others they have not. In general, a useful relationship can be obtained without incorporating these factors. Several investigators have studied the crown diameter-stem diameter relationship for single species and forest communities. Dawkins (9) compares the relationship for several tropical African species finding their relationships not significantly different. Bonnor (3) included a height variable in his studies and found that he could not combine species. Francis (14) noted, however, that as long as sampling technique is consistent, the results for different species may be combinable. Perez (30) found a meaningful relationship for each of 28 forest stands from Puerto Rico, Dominica, and Thailand, each often composed of several species, and when he combined all the data from these forest stands. Similarities between the trends of forests of the Amazon and Surinam were noted by Heinsdijk (19). The evidence suggests that it is reasonable to expect that a useful multi-species stem diameter-crown diameter relationship can be discovered for use in South Vietnam.

The form of the relationship that may be discovered was summarized in a review of literature by Dawkins (9). He suggests the form as:

1. linear from the origin
2. falling linear or curved
3. rising linear or curved
4. sigmoid.

It should be noted that the first three cases could be considered as segments of the latter, the sigmoid form. One might anticipate that the large emergent dominant trees may reach a point beyond which crown size fails to increase greatly although stem diameter may continue to develop.. Crown diameter growth may be limited by exposure to the elements and the mechanical support capabilities of the limbs. Very small suppressed trees may also show little relationship as indicated by Dawkins (9) because of the extremely difficult and varied growing conditions. Between these extremes the relation may be slightly curved or linear depending on the species and range of data employed for analysis. Many of the studies developed a significant linear relationship (5, 6, 7, 13, 14, 19, 25), but some have noted or suggested nonlinearities in their data (9, 14, 19). The linear relation has been defended as the most practical to use (19), but apparently none of these authors attempted a statistical comparison to determine if a nonlinear analysis might be more meaningful with better predictive properties. Perez (30) recently analyzed 28 forest stands using a logarithmic transformation and found very high correlation in all cases.

Since no field measures of tree DBH and crown diameter from Vietnam are known to the investigators, and since field measurement was impractical, existing information from other countries believed to have forest ecosystems similar in nature to those in Vietnam was used. Crown maps and stand structures obtained for plots from three locations in Thailand provided data from 353 trees comprising a wide variety of species growing under various ecological conditions. These forests and locations are:

1. Dry evergreen forest Sakaerat Experiment Station, Thailand
2. Dry dipterocarp forest Sakaerat Experiment Station, Thailand
3. High elevation moist evergreen forest Kao Yai National Park, Thailand.

The data for these trees consisted of the DBH from the stand tally plus the average of four crown diameter measures from the crown maps. The four crown measures were taken at 45° intervals, the first located at random.

The crown map from a fourth location, a low elevation moist evergreen forest at Khao Soi Dao Wildlife Sanctuary in Chantaburi Province, Thailand, was available, but unfortunately no stand tally with DBH was provided. Measurement of the crowns of these trees indicated that they were within the range of crown sizes obtained from the other three locations.

A final set of data was obtained from information published by Macabeo (27) in a study relating stump diameter and crown diameter of 200 Luan (Pentacme contorta) trees in the Philippines. In order to utilize these data an adjustment from stump diameter (assumed at 1.0 meters) to DBH (at 1.5 meters) was made. The adjustment was made by obtaining the following relationship between taper and stump diameter for 122 logs observed in the Vietnamese mill study:

$$Y = -0.04142 + 0.00300\ X$$

where: Y = taper, cm

X = stump diameter, cm

The coefficient of determination, (R^2) is 0.52, and the estimated variance about the regression is 0.034. The analysis found that this regression was highly significant compared to the critical F value at the .05 α level. This taper equation was subsequently used to adjust Macabeo's stump diameter data to DBH. The amount of the adjustment was small which would be expected since the taper between DBH and the assumed stump cut level occurred over a distance of only half a meter.

Vietnam and Thailand and the Philippines share many common tree species and forest types. In fact, Thailand was selected as the test site for extensive studies of aerially delivered herbicides because of these similarities (8). It would appear that use of data from these neighboring countries would be a reasonable approximation to information that cannot be directly sampled from Vietnam. Whether it is the best information or as good as direct information cannot be determined until ground sampling in Vietnam becomes feasible.

The DBH and crown diameter measures for the 553 trees were submitted for processing by analysis of covariance.

Using a linear model,

$$Y = \alpha + \beta X + e \qquad y = \text{dbh, cm}$$

$$x = \text{crown diameter, m}$$

Parameters were estimated for each location by ordinary least squares. The resulting equations for each location are given in the following table:

Location	Equation
Macabeo, Luan in the Philippines	$Y = 29.0739 + 4.7388\ X$
Dry Evergreen	$Y = -2.2053 + 3.8132\ X$
Dry Dipterocarp	$Y = 2.2840 + 3.7394\ X$
High elevation moist evergreen	$Y = 1.1614 + 4.6626\ X$

Analysis of covariance was used to determine whether the parameter estimates for these locations were significantly different. The analysis revealed that the slopes of the equations could be considered the same when compared with the critical F value at a .05 α-level. Intercepts, however, were found to be significantly different. This may in part be due to the Luan trees which were generally larger than those in the other three locations and when plotted appeared to be at the upper end of a combined non-linear trend.

The equation using the overall estimates for all locations is

$$Y = 12.3611 + 4.1449\ X;$$

coefficient of determination, $r^2 = 0.60$

estimated variance - 1061.5984

A plot of the residuals indicated that considerable nonlinearity was present hence the linear model was inappropriate.

A scattergram of the data suggested an allometric growth curve

$$Y = a\ x^b$$

where y = dbh, cm

x = crown diameter, m

a, b = parameters

would be more appropriate. A logarithmic transform (base 10) was applied to the data in order to test this model in a linear form (12).

$$\log_{10} Y = \log_{10} a + b \log_{10} X$$

Parameters were again estimated for each location by ordinary least squares. The resulting equations for each location are given in the following table.

Location	Equation
Macabeo, Luan in the Philippines	$\log_{10} Y = 1.1773 + 0.6975 \log_{10} X$
Dry evergreen	$\log_{10} Y = 0.4548 + 1.0302 \log_{10} X$
Dry dipterocarp	$\log_{10} Y = 0.7245 + 0.8130 \log_{10} X$
High elevation moist evergreen	$\log_{10} Y = 0.6461 + 0.9285 \log_{10} X$

Analysis of covariance to test whether the parameter estimates for these locations were significantly different revealed that both the slopes and intercepts were barely different when compared to the critical F value at a .05 α- level.

A plot of the residuals using the overall parameter estimates for all locations revealed no anomalies and a good fit was shown by a coefficient of determination of .92. The overall equation which should be adequate for most species and locations is:

$$\log_{10} Y = 0.7560 + 0.8954 \log_{10} X;$$

coefficient of determination = r^2 = 0.92;

estimated variance 0.1702

The much improved correlation obtained by using logarithmic transformation suggests the nonlinear trend of this wide range of data was strong enough that a linear relationship would be poor approximation. Many of the studies cited may have had a range of data along a relatively flat portion of an underlying nonlinear curve where a straight line approximation would be simpler to use. The results of this investigation tend to agree with the work of Perez (30) on 28 tropical stands who also used the logarithmic transformation.

The equation developed provides a strong prediction equation for stem diameter from crown diameter based on a multiplicity of species and ecological conditions believed to be similar to forest conditions of the Inland Forest of South Vietnam. The equation provides a simple means for translating crown diameter measurements for aerial photographs into stem diameters which may be used for volume computations.

The stem diameter-crown diameter relationship is nonlinear over the wide range of tree sizes used in this investigation. The linear relationships obtained by many other investigators may reflect confinement of their data base to a narrower range allowing a better straight line fit. These linear models would be hazardous to use to extrapolate beyond the data range because of possible divergence of the linear approximation from the underlying nonlinear curve. A nonlinear approximation such as the logarithmic transformation used in this study and by Perez would probably allow less hazardous extrapolation since the parameters may be closer to those of the true curve over a wider range.

D. Photo-sampling and Analysis of Tree Tallies

The estimate of dead tree numbers was made from 1:5,000 scale photographs by counting the visible dead trees of merchantable size. The sampling procedure is illustrated in Figure III-1.

Every third low-level photograph was sampled in order to avoid photo-overlap. Each frame was subdivided into 162 (9 x 18) quadrats of equal size, each quadrat corresponding to 1.5625 ha (about 3.9 acres). The total sample area covered by all films used was approximately 196,000 ha. In each third photograph, a count was made of the number of squares that fell under one of the twelve forest types defined by the Study Team. This count provided an estimate of the proportion of area in that photograph covered by each type present in the frame. The total area sampled was approximately 143,000 hectares. On each sample frame, one quadrat was randomly chosen in each forest type for a full count of all live merchantable size trees which were measured for crown diameter.

A rectangular area in the center of each photographic frame was used as the subsample area in which dead trees were counted. This subsample area was 12 quadrats by 5 quadrats and equivalent to 93.75 ha (approximately 230 acres) on the ground. Dead tree counts were limited to this center area in order to minimize edge effects and overlap errors. The total area of dead tree counting was 33,830 quadrats (52,859 ha., or 130,500 acres).

The live merchantable trees were measured with circular templates of 10 meter (minimum merchantable crown diameter), 20 meter and 30 meter diameters, which were reduced according to the scale of the photography, (e.g., a 30 meter diameter on a 1:5,000 photo measures 6 mm). The trees were placed into one of three possible crown classes:

$10 \text{ m} \leq \text{small} < 20 \text{ m}$

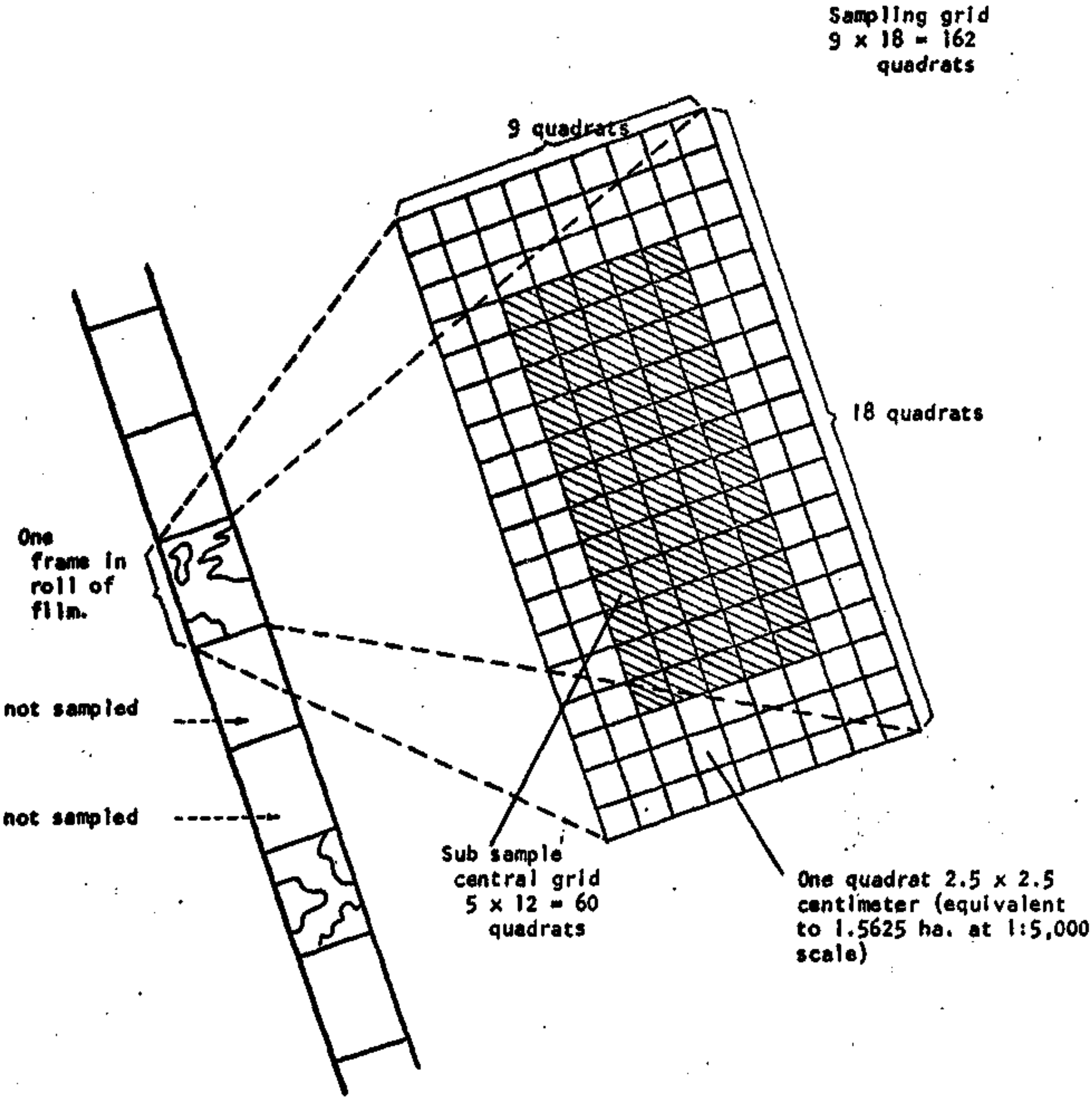


Figure III-1 Sampling technique used in tree counting: relative area of forest types is based on count of quadrats per type throughout whole (162 quadrat) grid. Dead merchantable trees were counted in all quadrats within central (5 x 12 quadrat) sub sample area. Live and dead merchantable trees, in three size classes, were counted in one quadrat per forest type in each photo frame.

$20 \text{ m} \leq$ medium < 30 m

$30 \text{ m} \leq$ large

The dead trees were carefully measured stereoscopically on a special series of reference low-level (scale 1:5,000) photographs which indicated which trees were of merchantable size. These photographs were used as merchantable size guides when observing dead trees from the sample film rolls of low-level photography.

Both live and dead tree counts were carried out on each photo and frequent comparisons of the mono and stereo appearances of given areas provided a good perspective for counting and measuring trees on one photo.

In each quadrat, dead merchantable trees were counted and recorded according to the forest types in each quadrat. Many quadrats had no dead trees of merchantable size. The frequency distribution of the number of dead trees of merchantable size per quadrat is listed in Table III-1.

The number of quadrats in which dead merchantable size trees were observed, converted into total hectares, is termed the "Observed Merchantable Mortality Area" (OMMA).

The estimates for each parameter for each forest type and for each film were obtained as follows:

Let Q_{ij} = total number of quadrats in forest type i in photograph j

q_{ij} = number of OMMA quadrats in forest type i in the central sample rectangle in photograph j

l_{ij} = average number of total merchantable trees in a quadrat of forest type i in photograph j

d_{ijk} = number of merchantable dead trees in forest type i in the k-th quadrat of photograph j

N = number of photographs sampled

Table III-1

Number of Quadrats Having Given Number of Dead Trees

# Dead Trees Per Quadrat	Code Number of Forest Type: 2	3	5	4	1	2_1	3_1	4_1	4_2	6	7	8	All Types
0	4897	4558	559	107	1225	2150	2115	124	339	2519	1751	827	21231
1	802	714	81	20	78	246	310	35	75	157	5	10	2533
2	289	254	25	11	16	114	123	28	48	55	4	4	971
3	124	107	4	10	13	47	65	8	25	21	1	2	427
4	56	45	2	7	6	23	22	4	13	18	2	1	199
5	37	26	1	6	2	17	14	0	15	8	0	2	128
6	12	19	1	3	2	8	9	0	3	5	1		63
7	10	15		1	2	2	5	0	4	2	1		42
8	4	10		0	1	8	2	1	0	1	0		27
9	3	7		2	1	1	4		1	3	1		23
10	5	3			1	0	1		3	1	0		14
11	6	1				0	2		0		1		10
12	0	0				0	1		0				1
13	2	1				1			1				5
14	1												1
15	2												2
16	0												0
17	1												1
18	0												0
19	0												0
20	0												0
21	0												0
22	0												0
23	0												0
24	0												0
25	1												1
26	0												0
27	0												0
28	0												0
29	1												1
Total Quads	6523	5760	673	167	1347	2617	2673	200	587	2790	1767	846	25680 = 40,125 ha

Then for forest type i:

Total type area within the 60 quadrat rectangle of the film	$T_i = \sum_{j=1}^{N} \frac{Q_{ij}}{160} (93.75)$
Total OMMA	$t_i = 1.5625 \sum_{j=1}^{N} q_{ij}$
Type area as a proportion of total area	$P_i = \frac{T_i}{93.75N}$
Mean number of total merchantable trees per hectare for the type	$L_i = \frac{\sum_{j=1}^{N} l_{ij}}{1.5625N}$
OMMA as a proportion of total type area	$p_i = t_{i/T_i}$
Total dead merchantable trees for type in sample	$D_i = \sum_{j=1}^{N} \sum_{k=1}^{N} d_{ijk}$
No. of dead merchantable trees per hectare for all hectares of type	$C_i = \frac{D_i}{T_i}$
No. dead merchantable trees per OMMA hectare of type	$C_i = d_{i/t_i}$

The variance of dead trees per total hectare and the variance of dead trees per OMMA hectare for each type were estimated using standard statistical techniques. The overall averages for the entire sample area for all types are estimates that were weighted as follows:

Mean number of live and dead merchantable trees per ha., for all types	$\sum_{i=1}^{12} P_i L_i$
Mean number of dead merchantable trees per total hectare	$\sum_{i=1}^{12} P_i D_i$

Mean number of dead merchantable trees per OMMA hectare $\sum_{i=1}^{12} p_i d_i$

The total variance values were estimated by pooling all the sums of squares to take into account within and between photograph and film variabilities.

These statistics are summarized in Table III-2. It should be noted that dead tree counting proceeded over the entire sample area; it was not limited to areas recorded as having been sprayed, because sprayed and unsprayed areas boundaries could not be distinguished on the photographs. Hence, no calculation is given, at this point, for dead trees relative to the area sprayed. This is dealt with in detail in Section V.

Table III-2

Summary of Merchantable Dead Tree Sample Data

Forest Type Code	Total No. of Sampled Hectares	Ratio of Type Area to Total Area	Mean No. of Live and Dead Trees/ha	Total OMMA (ha)	Ratio of OMMA to Total Area by Type	Total No. of Dead Trees Counted	No. of Mean Dead Trees/Total Area (ha)	No. of Dead Trees/ OMMA (ha)
2	12880	0.244	7.02	2496	0.194	2967	0.230	1.19
3	11851	0.224	10.86	2208	0.186	2582	0.218	1.17
5	1383	0.026	14.26	209	0.151	181	0.131	0.87
4	349	0.007	6.81	109	0.313	194	0.556	1.77
1	2766	0.052	1.20	223	0.081	264	0.095	1.18
2_1	5382	0.102	3.89	856	0.159	1051	0.195	1.23
3_1	5500	0.104	4.05	1022	0.186	1223	0.222	1.20
4_1	412	0.008	3.47	139	0.338	156	0.379	1.12
4_2	1207	0.023	2.99	344	0.285	527	0.437	1.53
6	5747	0.109	1.58	497	0.086	593	0.103	1.19
7	3640	0.069	0.07	30	0.008	63	0.017	2.11
8	1743	0.033	0.20	34	0.020	43	0.025	1.25
	52860	1.000	5.72	8167	.154	9844	0.186	1.21

E. Errors in Tree Counting and Volume Estimation as Influenced by the Size Distribution of Trees and Definition of Minimum Merchantable Size

The purpose of this section is to discuss some of the ways in which an error in tree count may occur in reference to the diameter frequency distribution of a forest stand. This discussion is limited to a presentation of how certain types of error in tree counting and ensuing volume estimates are affected by the diameter frequency distribution and definition of the minimum merchantable tree size.

One possible source of error in the damage assessment lies in the counting of trees above the minimum merchantable size standard of 10 meter crown diameter (45 cm dbh). The trees above this size standard were categorized as belonging to one of the following three size classes:

Small - trees from 10 meters up to 20 meters in crown diameter or roughly from 45 to 85 centimeters dbh

Medium - trees from 20 meters up to 30 meters in crown diameter or roughly from 85 to 120 centimeters dbh

Large - trees of 30 meters or more crown diameter or roughly 120 centimeters dbh or more.

These classes were defined on the basis of tree diameters observed in a utilization study of Vietnamese mills. These diameters were translated to crown diameters by means of the stem diameter crown diameter equation.

The volume of wood from the average tree in each of these classes that would be delivered to a South Vietnamese mill is

Small - 1.61 m^3

Medium - 3.67 m^3

Large - 4.61 m^3

These volumes were obtained from on site measurements in South Vietnamese mill yards during 1972.

The "J" Shaped Curve

In order to provide a basis for investigating the effects that various errors and misjudgments may have on the tree count, it would have been desirable to have had good stand composition data from a forest area in South Vietnam. However, since such data were unavailable from South Vietnam, data from the Cambodian inventory (32) was substituted. The 120 or more dbh class in this report was subdivided into three classes for the purpose of this study. The frequency relation of numbers of trees vs. tree size is shown in Figure III-2. Since the size classes of the Cambodian inventory do not coincide exactly with the three size classes defined above for this study, the following redefinition was necessary. These have been thus redefined:

Small - trees from 40-80 centimeters dbh

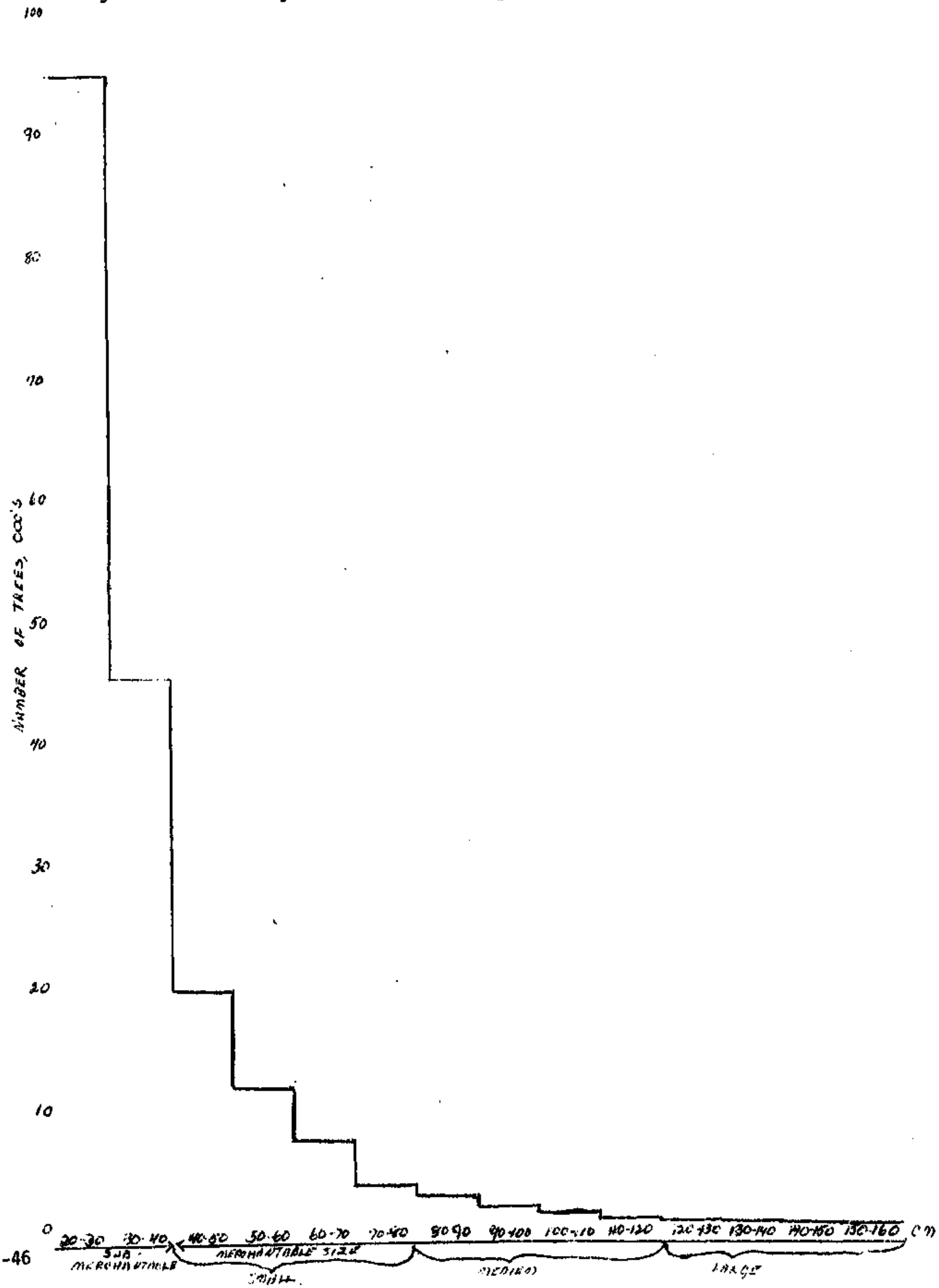
Medium - trees from 80-120 centimeters dbh

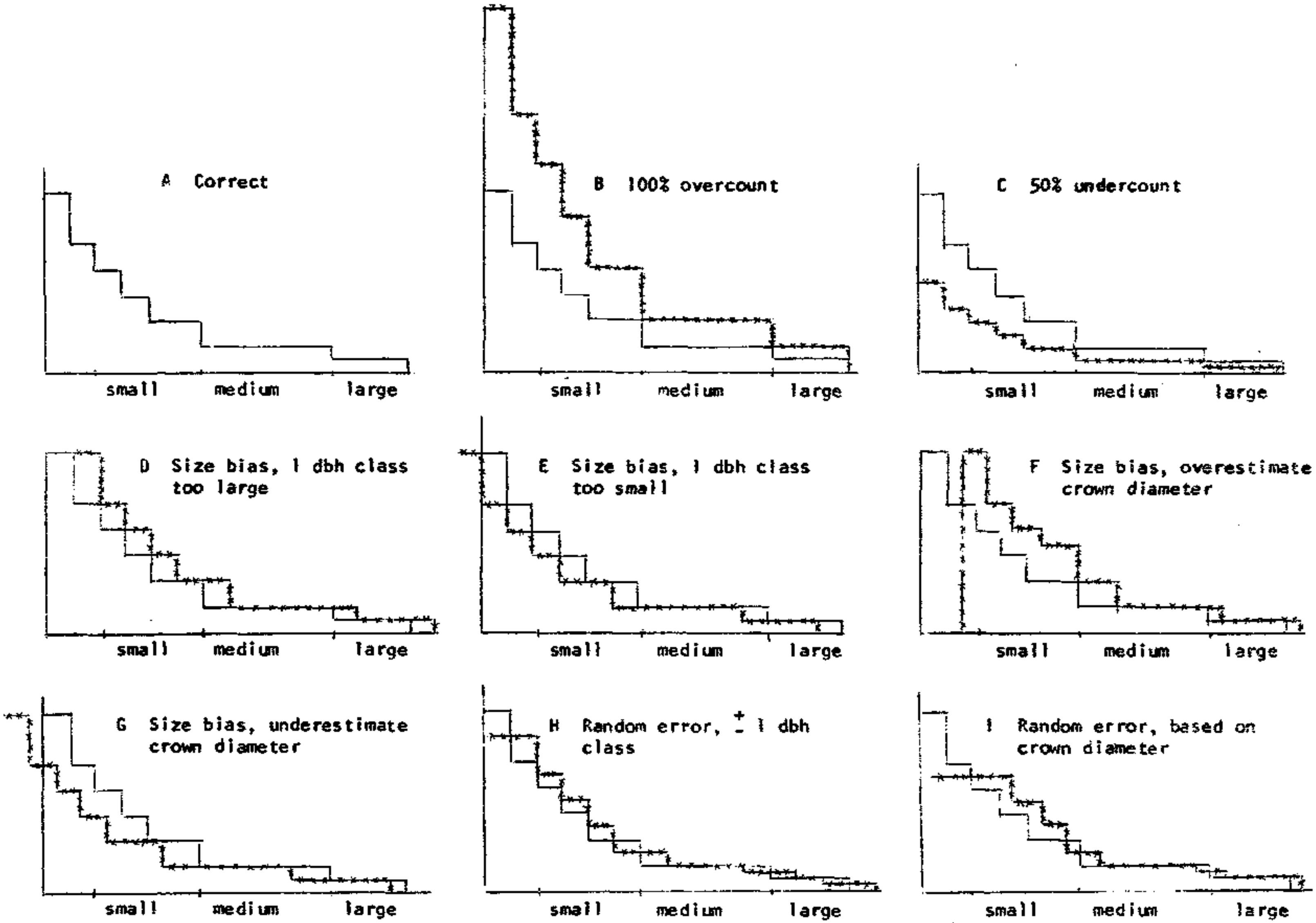
Large - trees of 120 or more centimeters dbh

These redefinitions will lead to overestimation of counts and volumes as compared to counts and volumes that would be obtained if the frequency distribution categories coincided with those used in the study. The magnitude of error introduced by this necessary approximation is not thought to be large and will not affect the illustration of the principles involved in counting errors to be discussed.

As a final note on Figure III-2, this is a common curve used by foresters and is usually called a "J" shaped curve. Typically, in forestry, the numbers of trees found in a forest diminish rapidly as one proceeds from small to large size. Since only some portion of the larger trees are of commercial use,

Figure III-2 J-shaped curve of Tree Frequency vs. of table Diameter.





** = error caused distribution

Figure III-3 Graphic Illustrations of Shifts Caused in J-shaped curve and count by size class by various estimation errors the commercial trees are usually at the tail of the curve where numbers of trees are relatively few. The definition of commercial size plus the shape of this curve have strong implications in error assessment.

Types of Error That May be Encountered

Area-related errors: An observer of trees using aerial photographs is subject to a number of errors which can be placed into two broad categories. First, there is error due to omitting or recounting a portion of the trees. This is likely to occur when the observer keeps faulty records and either skips over a portion of the film coverage or recounts it. This type of error illustrated in Figure III-3B. Figure III-3A represents a hypothetical "J" shaped curve. Figure III-3B illustrates the effect of recounting the entire population - a 100% overcounting error. The starred line outlines the shape of the frequency distribution caused by this error. Figure III-3C illustrates a 50% undercount error where half the area, hence half the trees were missed. In this case the error is more or less dependent on the area missed - assuming that the tree population is randomly distributed over the area. It is assumed in this example that the observer is not misjudging tree size.

Tree Size Misjudgment

The second category of error occurs when an observer misjudges tree size from aerial photographs. This can happen in several ways. He may consistently underestimate or overestimate tree size and his misjudgement may be the same magnitude for every size tree or it may vary with tree size or be affected by the number of trees present. Size misjudgment may occur through incorrect estimation of photograph scale, incorrect or improper use of measurement devices, or failure to frequently enough check ocular estimation of size. Even if the observer minimizes these factors, he may still be susceptible to random error at the size class boundaries. He may perceive some trees just below the boundary cutoff to be above the boundary and vice-versa. One may expect that this random error will tend to balance out but in fact may not, depending on the shape of the curve. With a J shaped curve it turns out that this random error will tend to increase the tree count.

In order to examine the effects of assumptions on how the size misjudgment occurs, the following examples were developed.

a. Size bias, same dbh error for all trees. In this case the observer may have misjudged the photo scale or used an incorrect measurement device so all tree crowns and hence dbh are judged to be too large or too small. Assume for the moment that an error of one dbh class is made. This type or error, if the observer has a bias which leads to estimating trees as one dbh class larger than they really are causes the J curve to be shifted to the right as illustrated by the starred line in Figure III-3D. This shift consequently leads to over-counting and overestimation of volume. Figure III-3D illustrates the effect of an observer bias which leads to estimating trees as one dbh class smaller than they really are. This shifts the J curve to the left and leads to under-estimation and undercounting.

A one dbh class size overestimation bias was applied to the Cambodian J-curve, the number of trees in the small medium and large classes tallied from the shifted curve and the volume was computed. Comparison with the un-biased correct count and volume indicates that overestimation by one dbh class leads to a 94% counting error and an 87% volume error. The volume error is less than the counting error because the principal component in the counting error is the smallest trees which have the least volume per tree. One should note that for a given J curve these results depend entirely on the cutoff point between the commercial and non-commercial tree size. If for example, the minimum acceptable tree dbh were 80 cm, the error in count and volume would be much reduced because of the flatness of the J curve above this level. Conversely, a minimum tree size cutoff of 30 cm would result in much more serious error because the curve is very steep in this area and the increment of trees included or excluded by even a slight shift would be very great.

A one dbh size underestimation bias was also applied to the Cambodian J-curve. Comparison with the unbiased correct count and volume indicates that underestimation by one dbh class leads to a 40% error in count and volume. This points out that underestimation of tree size leading to undercounting leads to much less serious error than overestimation of size.

To shed further light on this situation the relationship between crown diameter and tree dbh must be kept in mind. Solutions of this equation the boundaries between the tree size groupings indicate that a 1 dbh class error implies that the following crown width error is being made by the observer.

Crown error associated with ±1 dbh class error

small-subcommercial	2.4 meters
medium-small	2.7 meters
large-medium	2.8 meters

This information suggests that the same dbh error implies that the photo interpreter's tree crown size error is inversely related to tree size, that is, the observer makes his most precise estimation of the smallest trees and least precise estimation for the largest trees. This is a highly unlikely situation and indicates that this particular case though informative of the mechanics of these is unrealistic in practice.

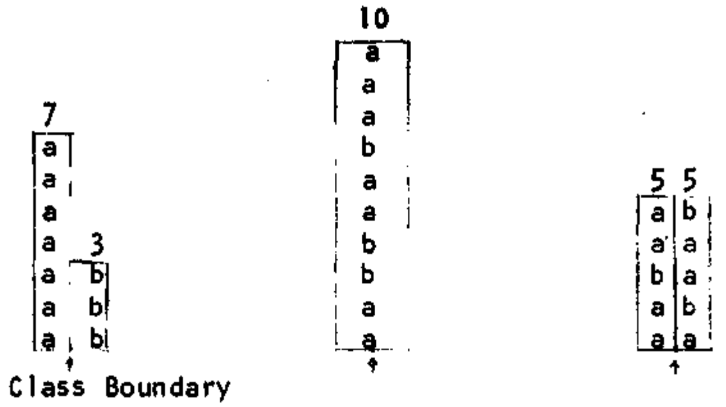
b. Size bias, error in dbh varies. In viewing trees aerially, the largest tallest trees present crowns with outlines that are easily seen, consequently they should be precisely measured. Smaller shorter trees may be partially obscured by their taller neighbors and in addition since there are so many of them, their crowns tend to merge so that crown outlines are indistinct, and hence more imprecisely measured. The starred lines in Figures III-3F and III-3G respectively illustrate the effect when the observer overestimates or underestimates tree size at the large-medium boundary by half a size class, at the medium-small boundary by 1 size class and, at the small-below minimum size boundary by 1.5 size classes. These dbh classes were determined by assuming that an observer makes the following crown size errors at the size group boundaries:

boundaries:	Crown Diameter Error
small-subcommercial	3.6 meters
medium-small	2.7 meters
large-medium	1.4 meters

These error ranges, substituted into the equation relating the crown diameter to dbh defined the dbh shifts indicated. The computational procedure outlined in the previous case was applied to the Cambodian J curve assuming these error shifts in dbh. In this case, overestimation of crown size led to nearly a threefold error in tree count and a 2.7-fold error in volume. Underestimation of crown size led to a much smaller error in count and volume, both being about 50%.

Random Error

Even if a well-trained careful observer minimizes or eliminates the types of errors discussed above, he may still be susceptible to random error where he has no bias but rather cannot accurately distinguish trees just above or below a boundary cutoff. In all the previous cases it has been that the only error was due to size bias but the observer was able to accurately place trees on either side of a bias boundary. Thus the discussion dealt with what may be termed mechanical curve shifts. However, the observer may still have difficulty distinguishing tree crowns within certain limits even if these mechanical biases are eliminated. In this case, the trees in the size classes within the error range on either side of the boundary may be regarded as a single population from which the observer randomly places trees into the classes. For example



The shape of the J curve suggests that this process will always shift the J curve to the right and thus will lead to overestimation of numbers of trees and volume. The starred line in Figure III-3H illustrates this situation when the observer is susceptible to a plus or minus one dbh class random error. When this process is applied to the Cambodian J curve, the result indicates that the random error leads to a 27% count overestimate and 23% volume overestimate.

This example is unrealistic since the same dbh error for all sizes implies that crown size estimation precision occurs in reverse order to that which would be expected. As explained earlier, the amount of random error may be influenced by the size and numbers of trees. Large tall trees, few in number, are more distinct to observe and measure whereas more numerous smaller trees are less distince and more difficult to measure. The starred line in Figure III-3I illustrates the J curve shift that occurs when the observer cannot distinguish at the large-medium tree boundary within half a size class, at the medium-small tree boundary within one size class, or at the small-below minimum size boundary within one and a half size classes. These correspond to observer crown diameter estimation errors of 1.4, 2.7, and 3.6 meters respectively.

When this process is applied to the Cambodian J curve, the result indicates that the random error leads to a 70% count overestimate and a 59% volume overestimate.

It is probable in practice that the type of random error discussed here are also operating when an observer also commits a size bias or area type error. These more complex combinations could be enumerated but it it felt that these simple cases cover the extremes and illustrate the principles and points involved.

Summary

The discussion focused on the possible impact of various error types that may occur during observation of tree counts from aerial photographs with emphasis on the relation to the J shaped curve. It is noteworthy that the % volume change is sometimes equal to but generally is less than the % tree count change which produced it. An experienced observer can eliminate all but the random error by use of good technique and instruments. The ability to minimize random error, which was demonstrated to lead to overestimation because of the shape of the J curve, depends on many factors including skill and experience of the observer. It has been noted that the error can be severe if the observer has a measurement bias whereby trees are thought to be larger than they really are. The error due to the reverse case is much less severe. The magnitude of error was shown to depend on the shape of the J curve and the definition of the minimum size merchantable tree. The magnitude of error diminishes rapidly as the minimum merchantable tree is defined at a flatter portion of the J curve.

1. Aldred, A. H. and L. Sayn-Wittgenstein. 1972. Tree Diameter and Volume From Large-Scale Aerial Photographs, Information Report, Forest Management Institute, Ottawa, No. FMR-X-40, pp 1+.

2. Avery, T. Eugene. 1968. Interpretation of Aerial Photographs, 2nd. Edition.

3. Bonnor, G. M. 1968. Stem Diameter Estimates from Crown Width and Tree Height. Commonwealth Forestry Review. 47(1) (131):8-13.

4. Boon, D. A. 1970. A Critical Review of Timber Survey Methods in Tropical Rainforest, ITC Publications(International Training Center), Delft, Netherlands, Series B. No. 58, October.

5. CheYeom, F. B. and K. Sandrasegaran. 1966. Growth and Yield of Yemane, Malayan Forester 29(3):140-153.

6. Curtin, R. A. 1964. Stand Density and the Relationship of Crown Width to Diameter and Height in Eucalyptus Obliqua. Australian Forestry 28(2):91-105.

7. Curtin, R. A. 1970. Dynamics of Tree and Crown Structure in Eucalyptus Obliqua. Forest Science 16(3):321-330.

8. Darrow, R. A., Truchelut, G. B., Bartlett, C. M. 1967. Defoliation of Tropical Evergreen Forest in Thailand. Dept. of the Army, Ft. Detrick, Md. Project ARPA Order 423.

9. Dawkins, H. C. 1963. Crown Diameters: Their Relation to Bole Diameters in Tropical Forest Trees. Commonwealth Forestry Review 42(4)(114):318-333.

10. de Rosayro, R. A. 1958. Recent Advances in the Application of Aerial Photography to the Study of Tropical Vegetation. From the Proceedings of the Symposium on Humid Tropics Vegetation, Tjiawi (Indonesia), Dec. Unesco Science Cooperation Office for Southeast Asia.

11. ______________ 1959. The Application of Aerial Photography to Stockmapping and Inventories on an Ecological Basis in Rain Forest in Ceylon. Emp. for Rev. 38:141-147.

12. Draper, N. R. and H. Smith. 1966. Applied Regression Analysis. John Wiley and Sons, Inc., New York. 407 pp.

13. Fox, J. E. D. 1968. Some Data on the Growth of Anthocephalus Cadamba in Sabah. Malayan Forester 31(2):89-100.

14. Francis, E. C. 1966. Crowns, Boles and Timber Volume from Aerial Photographs and Field Surveys. Commonwealth Forestry Review 45(1)(123):32-66.

15. Ferree, M. J. 1953. A Method of Estimating Timber Volumes from Aerial Photographs. Tech. Pub. #75 of State Univ. of N.Y., College of Forestry at Syracuse.

16. Gerrard, D. J. 1969. Error Propagation in Estimating Tree Size. Photogrammetric Engineering, Vol. 35(4), April. pp. 355-362.

17. Hannibal, L. W. 1952. Aerial Forest Photo-Interpretation in Indonesia. Docum. FAO Asian Pacific Forestry Commission, No. 75.

18. Heinsdijk, D. 1955. Forest Type-Mapping with the Help of Aerial Photographs in the Tropics. Tropical Woods 102:27-46.

19. ______________ 1957/58. The Upper Story of Tropical Forests. Tropical Woods. 107:66-84, 108:31-45.

20. ______________ 1960. Surveys Applicable to Extensive Forest Areas in South America. Proc. Fifth World Forestry Congress. Vol. 1 (sect. A&B), pp. 251-256.

21. Holdridge, L. R. et al. 1971. Forest Environments in Tropical Life Zones: A Pilot Study, Pergamon Press, Oxford.

22. Honer, T. G. 1966. Standard Volume Tables and Merchantable Conversion Factors for the Commercial Tree Species of Central and Eastern Canada, Information Report, Forest Management Institute, No. FMR-X-5.

23. Howard, J. A. 1970. Aerial Photo-Ecology. Faber and Faber, London 325 pp.

24. Husch, B. 1965. Forest Inventory Planning. Unasylva, Vol. 19 (2), No. 77, pp.65+.

25. Kwan, Wong Yew. 1966. Crown Diameter/Bole Relationship of Dyera Costulata and Its Planting Distance and Crop Density. Malayan Forester 29(3):163-169.

26. Loetsch, F. and K. E. Haller. 1964. Forest Inventory Volume I BLV Verglagsgesellschaft Munchen Basel Wien.

27. Macabeo, Marcelino E. 1957. Correlation of Crown Diameter with Stump Diameter Merchantable Length and Volume of White Luan (Pentacme contorta (V ID) Meri & Rolfe) in Tagkavouyan Forests, Quezon Province. The Philippine Journal of Forestry. Nos. 1-2 (13):99-117.

28. Nyyssonen, Arne. 1961. Survey Methods of Tropical Forests, FAO Docum. Rome.

29. Paijmans, K. 1951. Een voorbeeld van interpretatie van luchtfoto's van oerwoud: Het Malili-complex op Celebes. (Summary: Interpretation of Aerial Photographs in Virgin Forest Complex. Malili Celebes. Tectona, pp. 111-135.

30. Perez, Jose. W. 1970. Relation of Crown Diameter to Stem Diameter in Forests of Puerto Rico, Dominica and Thailand. In Odum, H. T. and Pigeon, R. F. A Tropical Rain Forest - A Study of Irradiation and Ecology at El Verde, Puerto Rico. Div. of Tech. Info. U. S. Atomic Energy Commission.

31. Richards, P. W. 1952. The Tropical Rain Forest: An Ecological Study, Cambridge.

32. Rollet, B. 1962. Report to the Government of Cambodia Forest Inventory of the East Mekong. Translation by Jose G. Flores (1973).

33. Sayn-Wittgenstein, L., and Aldred, A.H. 1967. Tree Volumes from Large Scale Photos, Photogrammetric Engineering, Vol. 33, No. 1 pp. 69-73.

34. Spurr, S. H. 1960. Photogrammetry and Photo-Interpretation, 2nd. Ed. The Ronald Press, New York. 472 p.

35. Stellingwerf, D. A. 1964. Investigations Concerning Tree Height Measurements and Estimations, ITC Publications, Series B., No. 22, Delft (The Netherlands) Spring.

36. Stellingwerf, D. A. 1971. Aspects of the Use of Aerial Remote Sensors in Tropical Forestry, International Union of Forestry Research Organizations (IUFRO) Section 25. Working Group on Application of Remote Sensors in Forestry, Application of Remote Sensors in Forestry, Freiburg i. Br.

37. Swellengrebel, E. J. G. 1959. Large Scale Aerial Photos in Brit. Buiana Forestry. Empire Forest Review 38: 54-64.

38. Williams, L. 1965. Vegetation of Southeast Asia: Studies of Forest Types. Agric. Res. Serv.: USDA. Under ARPA Order No. 424 Department of Defense.

IV. Inventory of the Inland Forests of South Vietnam

I. INTRODUCTION

The task of the forestry study team was to estimate the damage to inland forests of South Vietnam due to military use of herbicides. The damage was to be assessed in terms of merchantable volume and loss of growing stock. For this purpose, a general inventory of the forests would have been useful. Such an inventory was not available. However, in addition to the data obtained from photographic samples, extensive inventories were available for two other large regions of the Indo-China peninsula representing comparable forests. These were the FAO-sponsored inventories of Northeast Thailand and the region of Cambodia east of the Mekong River. These two inventories were used as a basis for the design of the special purpose inventory of South Vietnam. Since the forests of South Vietnam were not accessible for field sampling, the special purpose inventory was based upon extensive aerial photographic sampling.

This section will deal with these inventories in more detail. What we need to concern ourselves with at this point is the way in which the basic data from the extensive photographic samples was used for obtaining inventory volume estimates.

The aerial photographic data was classified into forest type strata, and for each of these strata, trees were counted into small, medium and large crown-size classes (see the section on aerial photograph interpretation for further details), it behooved us to obtain volume estimates for each of these size classes. However, prior to elucidating the methodology used for obtaining these estimates, a few generalities need to be discussed about tree volume estimation in general, and the factors that influence the development of criteria for estimating various kinds of volumes, namely: total volume, inventory merchantable volume and exploitable merchantable volume.

II. Generalities about Tree Volume Estimation and Merchantability Standards

Tree volumes can be determined in a number of ways depending upon the objective of the exercise. Ecologists are frequently interesred in the total volume of a tree or sometimes in its weight or biomass. For general inventory purposes, foresters are commonly interested in the volume of the stem. They may be concerned with the whole stem or with only that portion of the stem that is between the top of the stump and the base of the crown (the bole). For special inventory purposes the forester may be interested only in that portion of the stem that is useful for manufacture into a particular product (sawlogs for manufacture into lumber or peeler logs for manufacture into veneer). Grades of sawlogs or peeler logs may be restricted as to length or diameter.

A. Stem Analysis and Stem Volumes

Figure IV-1 is a stem analysis curve for a Dipterocarpus tuberculatus tree from Thailand. This is a representative of a common type of Southeast Asian tree. The The total volume of the stem of this tree can be determined by integrating the volume of sections representing .01 of the total height. Using this analysis, the volume is calculated to be $4.96M^2$ cubic meters. Total volume of trees such as this may also be estimated by using logarithmic regression equations based upon the height and the square of the diameter. This is a statistical procedure commonly used in ecological studies to determine the biomass of a tree. Sanga Sabhasri (1968), in a study of the primary production in dry-evergreen forests at Sakaerat, Thailand, developed a regression equation of the form:

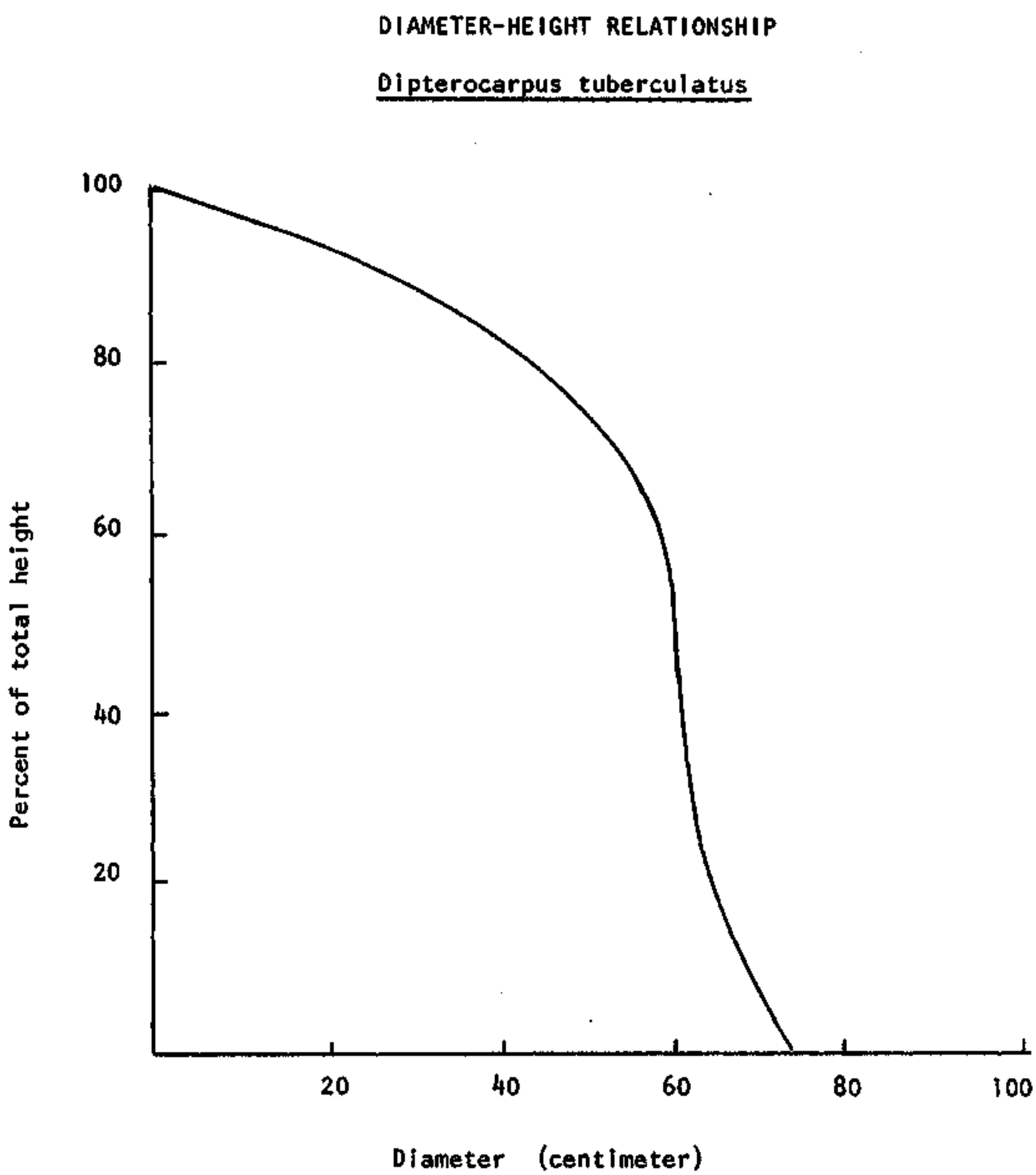
$$V_s = .00008009\ (D^2H)^{.92973} \qquad (1)$$

where: D = diameter at breast height in cm

H = total height in meters (M)

V = total stem volume in M^3

Figure IV-1


DIAMETER-HEIGHT RELATIONSHIP
Dipterocarpus tuberculatus
100
80
60
40
20
Percent of total height
20
40
60
80
100
Diameter (centimeter)

Solving this equation for the tree represented by the forementioned stem analysis curve, yields a value of 4.94 cubic meters. This value is in good agreement with the value obtained by the integration procedure. Sabhasri, et al developed a similar regression equation for estimating the volume of the branches on such a tree. This equation is:

$$V_B = .006002\ (D^2H)^{1.027}$$

Solving this equation for the same tree, gives a value for branch volume of 1.41 cubic meters. Combining the results of these two equations, yields a value for stem and branch volume of this tree of 6.35 cubic meters. This type of calculation is useful in estimating the sum of the merchantable and non-merchantable volumes of the tree.

Various values for the merchantable component of the tree can be determined depending upon the criterion of merchantability that is used.

One method for computing the gross merchantable volume on an inventory basis is illustrated in Figure IV-2. Here it is assumed that the portion of the stem between a one meter high stump and the base of the crown is considered to be a single log. The base of the crown is at 60 H_t percent of the total height of the tree. The volume of this log calculated by the integration method would be 3.74M^3 cubic meters. On this basis, the nonmerchantable part of the tree would be 2.61 cubic meters, of which 1.21 cubic meters is in nonmerchantable stem, and 1.41 cubic meters is in branches. The nonmerchantable components have the potential, whether realized or not, of being used directly as fuelwood or being converted to charcoal.

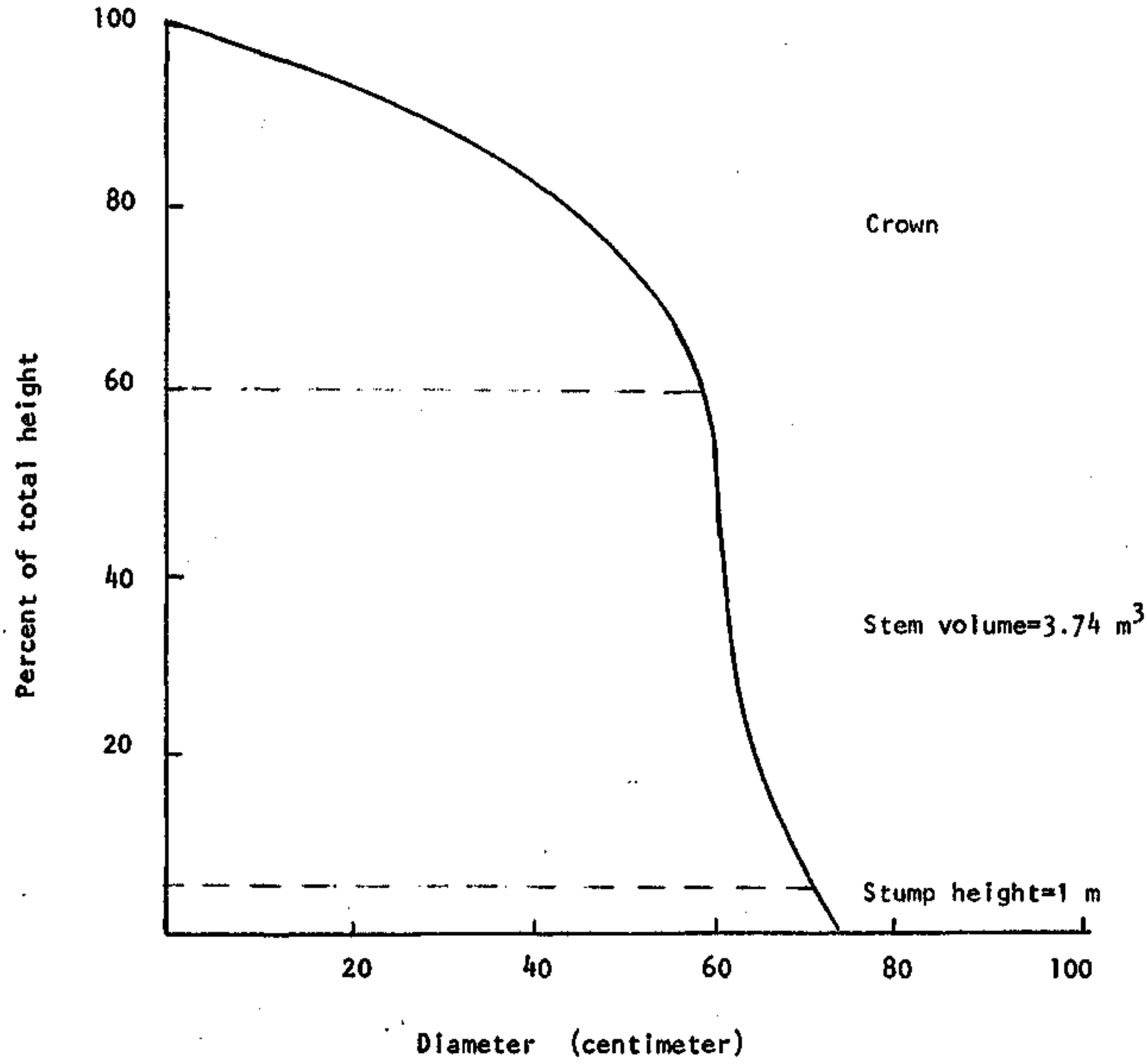
Logs are generally bought and sold in Southeast Asia on the basis of a log scale. The Hoppus log scaling rule is usually used in this part of the world as a basis for marketing. This log rule calculates the squared volume of the log. It is determined by measuring the girth at mid-length of the log and the length of the

Figure IV-2

DIAMETER-HEIGHT RELATIONSHIP

INVENTORY MERCHANTABLE VOLUME

<u>Dipterocarpus tuberculatus</u>



log, computing the volume of a cylinder with these two dimensions and then reducing the scale volume to .785 of the cylinder volume to account for loss in slabs in the mill. The volume of the tree-length log, as it would be marketed, would then be:

$$(\pi)\ (.^{53}/2)^2(16.4)\ (.785) = 2.84 \text{ cubic meters}$$

This method is equivalent to solving the following equation:

$$V = 0.623\ D^2L$$

where: V = Hoppus volume in M^3

D = diameter at midlength in meters

L = length of the log in meters

In the example cited above, the Hoppus volume using this latter equation would be 2.87 cubic meters which is in good agreement with the first method results.

In Thailand, inventory merchantable volumes are based upon the addition of the volumes of five meter logs in the clear bole. For this sample tree, the merchantable volume, Hoppus scale, based upon five meter logs would be:

Log 1

$$(\pi)\ (^{.6}/2)^2(5)(.785) = 1.11\ M^3$$

Log 2

$$(\pi)\ (^{.55}/2)^2(5)(.785) = .93\ M^3$$

Log 3

$$(\pi)\ (^{.49}/2)^2(5)(.785) = \underline{.74\ M^3}$$

Total $2.78\ M^3$

This form of a merchantable log inventory is suitable in Thailand, where logs are generally bought and sold in five meter lengths. In South Vietnem, where the practice is to market logs generally in tree lengths, the first type of computation would be most appropriate.

One of the problems encountered by foresters engaged in forest inventory is that of determining an appropriate tree volume estimation. The <u>Dipterocarpus</u>

tuberculatus tree just discussed has a substantial butt swell and pronounced taper. This is a common structure among the tree species of Southeast Asia though it is by no means universal. Some trees have relatively little buttressing and little taper resulting in boles that approach a cylindrical shape. There are so many different species, genera and families of trees in tropical forests that a whole spectrum of tree forms is common. Even within a given species, ont tree may be quite different in stem form from another depending upon the abiotic characteristics of the environment in which each grows.

Figure IV-3 represents a stem analysis curve for a Dipterocarpus spp tree from Thailand. This is another type of tree common in Southeast Asia. This tree has the same total height and diameter at breast height as the tree represented in Figure IV-1 and its first limb is also at 60 percent of the total height of the tree.

The total volume of this tree, computed by integrating segments representing one percent of the total height, is 7.92 M^3 cubic meters. This contrasts with the 4.96 value obtained for the Dipterocarpus tuburculatus tree previously analyzed. Since the two trees have the same diameter and total height, the estimate of total volume obtained from the allometric equation of Sabhasri would be the same, namely; 4.94. Obviously this allometric equation would seriously underestimate the total volume of this tree.

The volume of the bole between top of stump and base of crown is 5.9214 cubic meters as compared with 3.74 cubic meters for the first tree.

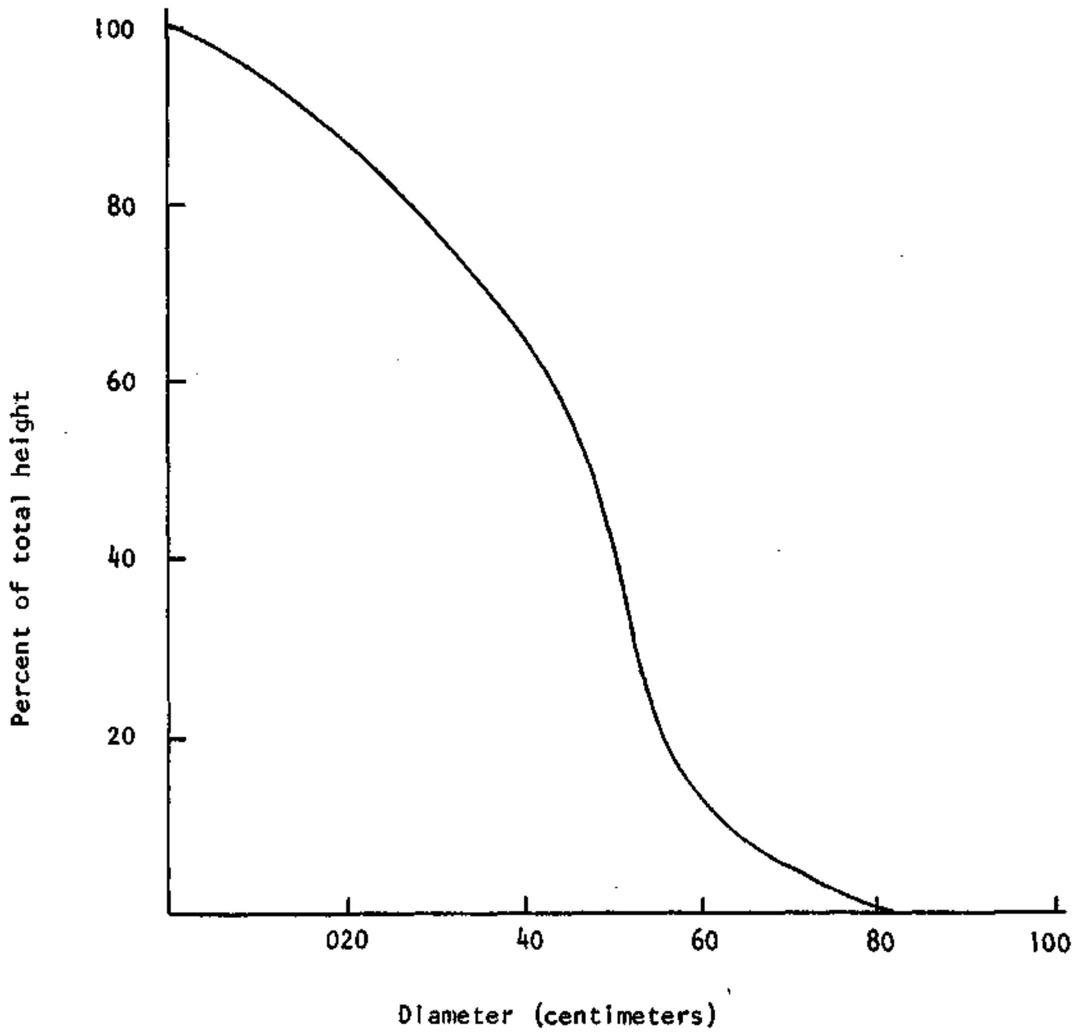
The full-length log, scaled according to the Hoppus rule for this tree, would yield a value of 3.89 cubic meters. The same tree scaled as three 5 meter logs would give a merchantable volume of 4.68 cubic meters.

The inventory of Northeast Thailand includes two volume tables that represent different tree forms. These tables are based upon the mensurational definitions of merchantability, including the assumption that merchantable portions of the bole are

Figure IV-3

DIAMETER-HEIGHT RELATIONSHIP

Dipterocarpus



in five-meter log components. The volume table value (Hoppus) for a Pluang tree (Dipterocarpus tuburculatus) of 70 cm dbh and 5 logs is 3.405 compared to the actual volume for this tree from the stem analysis of 2.78. For the second tree, the value from the volume table for Yang (Dipterocarpus sp.) is 4.772, while the actual volume from stem analysis is 4.68 cubic meters.

B. Factors of Exploitable and Inventory Merchantable Volumes

The exploitable merchantable (net) volume of a tree, at any given point in time, may be quite different from the inventory (gross) merchantable value. In the tropics, many trees have heavily buttressed trunks. If the manufacturing companies are highly discriminating with respect to quality and product yield, the de facto merchantable volume is likely to be much lower than the inventory merchantable volume. For example, when trees have heavy buttresses, these may be unacceptable in the market. The logger, responding to this market situation, may cut very high stumps (up to 2 or 3 meters) or he may fell the tree at the conventional stump height and then "long butt" it in the forest before loading out the usable component. That is, he cuts the tree at the usual or in some cases, specified stump height and then cuts off that portion of the butt of the log which is in the buttress and is not saleable in the market, shipping the merchantable remainder to the factory. This effectively reduces the exploitable merchantable volume to a value well below the inventory merchantable volume.

Many tropical trees have large and heavy crowns. In the falling operations the bole breaks below the base of the crown sometimes causing a shattered bole. This loss of useful volume also results in an exploitable merchantable volume that is substantially less than the inventory merchantable volume because part of the upper portion of the clear bole has to be discarded.

A common defect, among mature and over-mature tropical trees of some species, is extensive butt rot caused by fungal infection. When this is present, the tree, after being felled in the forest, must be long-butted to remove the decayed portion since this defective wood is not acceptable in the market place. This is a particularly important problem in Southeast Asia where a secondary genus, Lagerstroemia, is especially susceptible to this defect. In some forest types, particularly in what Rollet calls the semi-dense and intermediate forests, Lagerstroemia sp. represents the predominant trees of merchantable size. In other types, where Dipterocarps were the predominant species in the forest, high-grading of the forest has, over many years, increased the number of Lagerstroemia trees in the emergent canopy to a very large fraction of the stand total. This genus represents an important example of a situation in which exploitable merchantable volume will be much less than the inventory merchantable volume.

The two sample trees already used for illustrative purposes may be analyzed to indicate the way in which exploitable merchantable volume may differ from inventory merchantable volume. Suppose that instead of cutting the trees at a standard one-meter stump height, the trees were in fact cut above the butt swell--a common practice in tropical forest utilization. Under these circumstances, the first tree would have an exploitable, merchantable volume (Hoppus) of 1.86 cubic meters. The second tree, with a much smaller buttress and less taper, would have an exploitable merchantable volume of 2.66 cubic meters.

There are a number of other factors that can be expected to reduce the exploitable merchantable volume below the inventory merchantable volume. The minimum acceptable small end diameter may be less than the diameter at the base of the crown. Decay, insect damage or physical damage due to contact with adjoining trees may cause some part of the inventory merchantable bole to be left in the forest as woods residue and further reduce the exploitable merchantable volume.

The greater the supply of trees compared to the demand for wood, the more particular is the market and the greater is the difference between exploitable merchantable volume and inventory merchantable volume. The exploitable merchantable volume at any given time, is also a function of the number of different kinds of wood-using industries that are competing for the raw material. In South Vietnam, the supply of merchantable wood exceeds the demand by a large margin even with the nation's history of heavy exploitation. In addition, there is essentially no monitoring of cutting. The Government of South Vietnam cannot supervise the forests on which it lets concessions and timber cutting rights. Accordingly, the loggers are free to engage in essentially unrestricted high-grading. Only the most profitable logs are removed from the forest. Because logging is conducted in forests that are also the centers of combat, and because the loggers are constantly moving between zones that are controlled by opposing forces, the logging enterprise is very dangerous to the personnel involved. In addition, the very heavy multiple taxation system imposes a heavy burden on timber removed from the forest. Understandably, the logger, essentially unrestricted except for the limitations of security, commodity value and his own enterprenurial instincts, is unlikely to engage in the difficult and dangerous task of transporting wood from forest to mill unless it has substantial acceptability and value. All of these factors militate against the transport of defective material and in favor of low values for exploitable merchantable volume.

As previously indicated, the exploitable merchantable volume depends upon the variety of manufacturing enterprises using the wood. In South Vietnam, the vast majority of the manufacturing plants product custom-sawn lumber. Only one plywood plant exists in the country. Located at Bien Hoa, it uses only one species of wood, Anisoptera. A change in the nation's mix of wood-using industries would change the utilization standards. The addition of more plywood plants using other species, or of one or more pulp mills, would materially modify the level of exploitable merchantable volume.

Speaking to this question, Gartner and Beuschel (1962) describe the relationship between inventory merchantable volume and exploitable merchantable volume, in their report on the forest inventory of northeast Thailand, as follows"

> At the time being, predominantly saw timber is exploited in the forests of Thailand. Therefore, only the volume of merchantable bole is of interest and consequently, it must be the unit of meaning of a volume table. But even if the volume of the merchantable bole is considered as the unit of measuring, the total merchantable volume of the bole, or only that part which is presumably exploited under the present system of exploitation, can be used as the unit. Since logging and lumber manufacturing operations are improving permanently, the volume which will be obtained from a certain tree by the present system of exploitation. It seems, therefore, to be much more suitable to calculate the volume tables in terms of "cubic meters of total merchantable volume under bark." The volume of the merchantable bole between the normal stump of 30 cm height above ground level and the upper limit, which is given by the beginning of the crown, defects of the bole, or a minimum diameter of 28 cm outside the bark, is the so-called "total merchantable volume". If the merchantable roundwood going to be extracted under a certain system of exploitation is requested as a final result of a timber cruise, the total stock compiled by aid of the volume table in "total merchantable volume" has to be adjusted by a special "exploitation factor". This factor is calculated as a quotient of the "presumable exploitable merchantable volume" and the "total merchantable volume". The exploitation factor will vary in different areas according to the system of exploitation. It can be determined easily, if the actually exploited volume of some sample tress in the exploitation area are measured and put in relation to the corresponding volume of these trees. Thus, both requirements can be satisfied, because the volumes of the tables are independent of the systems of exploitation and the presumably exploited merchantable volume can be calculated by aid of an exploitation factor.

Rollet, discussing this same relationship between inventory merchantable volume and exploitable merchantable volume with respect to the inventory of Cambodia east of the Mekong, states, "...the real value of these forests is still overestimated. Prolonged observations on logging yards would be the only means of providing some idea on the probable proportion of'cull wood' ."

In the absence of a general field based-inventory of South Vietnam, and since there was no rational basis for speculating about the future structure of the country's wood using industries, nor would this be appropriate for a damage assessment, the forestry team based its inventory of exploitable merchantable volume upon the current utilization standards being used in the exploitation of South Vietnam forest products. The Thailand and Cambodian inventories were used to make judgments concerning stand structure while estimates of the utilizable components of the individual tree volumes were based upon a utilization study made in the log yards, log landings and mill yards of South Vietnam during the winter of 1972-1973. This survey was conducted by the forestry study team at forty-four sawmills and the only plywood factory in South Vietnam to determine the criteria for current utilization standards of merchantable trees. Information obtained in the study provided a basis for estimating the mix of species currently (1972-1973) being used in the mills of South Vietnam and the exploitable merchantable volume of trees harvested for lumber and plywood from South Vietnam's forests.

C. Log Quality Classes of South Vietnam

The quality classes used are those that commonly provide the basis for marketing trees, logs and product in South Vietnam. The quality classes are described by McKinley (1957) as follows:

Class A. Luxury Woods: Woods in popular demand because of the unusual contrast of color in venation, distinctive fiber arrangement, and adaptability to the arts, and, above all, the familiarity of the trade with the wood.

Class 1. Wood characterized by great resistance to insect and borers, Carpenter ants, termites, beetles and to decay, by high density, strength, and toughness. Most of these woods are used for durable construction.

Class II. Woods utilized particularly in protected construction work because of their low decay resistance and for ordinary cabinet work; hard, medium heavy; cheaper than Class 1 and Luxury Woods.

Class III. All woods called "white", soft and rather light. These woods are used in making packing cases, framing and light temporary construction. Low resistance to insects and decay.

The merchantability of a tree may be judged in the first instance by noting whether it is of a species for which there is a demand in the market place. Its merchantability will also depend upon its size. For conversion to such products as lumber and plywood, the manufacturers, who buy the product of the tree as industrial raw material, typically insist that a log, i.e., the merchantable portion of the tree, meet specified minimum size requirements. Finally, the merchantability of a tree, even when it is of an acceptable species and an acceptable size, may be determined on the basis of its quality with respect to the presence or absence of such defects as decay, insect damage, fire scars, knots, spiral grain, or physical damage such as breaks or abrasion scars.

Classification of species according to quality criteria, such as the wood previously described, is a partial basis for determining acceptability in the market place. In general, only Luxury, Class I and Class II woods are acceptable for manufacture. That is not to say that all of these woods are marketable in the quantities available in the forest. As previously noted, in Thailand, Lagerstroemia represents 26 percent of the merchantable-size standing trees, and yet barely 14 percent of the wood is actually being used in the market place of this species.

Among the Class II Woods, Anisoptera, the only species currently being used for plywood, represents 20 percent of the currently used volume of all classes, and Dipterocarpus, a commonly used lumber species, represents 21 percent of the currently used volume of all classes. According to McKinley, there are 170 separately distinguished woods recognized in South Vietnam as belonging to the Class III and better categories. Eleven are included in the Luxury Class, 28 in Class I, 38 in Class II, and 93 in Class III. The utilization study made by the forestry task force found only 16 of these separately distinguished South Vietnam woods being used in the sawmills and plywood plant studied. These represented two luxury woods, four Class I woods, and four Class III woods. Seventy-eight percent of the logs tallied in the study were in one of 5 woods as distinguished in the South Vietnam industrial market.

III. Estimation of Tree Volumes for South Vietnam

It is apparent from the previous discussion, that the various parameters needed for obtaining the various volume estimates for the three stem size classes are the following: total heights, inventory merchantable heights, exploitable merchantable heights, diameters at breast height and some measure of form for each stem size class.

A. Estimation of Tree Heights

Because total height data from Vietnam were not available, these were acquired from study plots in Thailand. Sixty trees from different species and diameter classes were analyzed, using one of the models explained by Sandresegaran (1971) for height-diameter relationships in West Malaysia. Regression analysis of these data resulted in the following parameter estimates:

$$H_t = 6.82844 \ln D$$

where H_t = total height, in meters

D = diameter at breast height, in centimeters

The correlation coefficient of 0.955 and a satisfactory examination of residuals indicated the adequacy of this equation for predicting total heights from DBH. The predicted total heights for the three class categories are given in Table IV-1.

Using this same set of data, average proportions were estimated that related merchantable height to total height. These proportions, in turn, were used to estimate inventory merchantable heights for the three stem diameter classes. The relationship used was the following:

$$H_I = \beta H_T$$

where, H_I = inventory merchantable height for each size class

H_T = inventory total height for each size class

β = regression parameter estimate

The values of β estimated for each size class were as follows:

Size Class	β-estimate
Small	0.498
Medium	0.574
Large	0.653

Inventory merchantable heights for each size class are summarized in Table IV-1.

Exploitable merchantable heights were obtained directly from the survey the forestry study team conducted at forty-four sawmills and the only plywood factory in South Vietnam.

Ralston and Tho (1970) report that there were 436 sawmills in South Vietnam in South Vietnam in 1970. Assuming that this number had not changed greatly by the winter of 1972-73, when the utilization study was made, the sample of mills was approximately ten percent of the active sawmills. The sawmills studied included 36 in the Saigon - Gia Dinh area and eight in Bien Hoa. The exploitable merchantable heights were obtained by measuring 1154 tree length logs of 16 different species at these mills. These statistics are summarized by species in Table IV-4 and by commercial log quality class in Table IV-5. The average exploitable merchantable heights for each size class is given in Table IV-1.

Table IV-1. Tree Heights for each Size Class

Stem Size Class	Heights (meters)		
	Inventory Total	Inventory Merchantable	Exploitable Merchantable
Small	28.54	14.19	8.73
Medium	31.61	18.14	8.21
Large	33.24	21.71	6.48

The exploitable merchantable height is seen to diminish with increasing diameter class. This may seem contrary to expectations but may be explained by several factors. First, the more expensive luxury class species (e.g. Dalbergia sp.) fall into the small class because heavy historic exploitation has already removed layer stems. Furthermore, since this wood is so valuable, loggers find it profitable to remove pieces in log form to a smaller minimum top diameter than other species, thus increasing the utilized length. In the larger size classes, Lagerstroemia sp. is a major component and the group is well known for butt rot and cull in the larger specimens which combine to greatly reduce the utilized length. A final factor that should be noted is that larger trees generally are more greatly damaged upon ground impact when felled. This damage includes splitting and breakage at both ends of the tree. These damaged pieces are bucked off by loggers and left behind and only a relatively small portion of the total length is actually removed.

B. Estimation of Form

Since size class mean diameters were set by the size categories themselves, the only additional information needed to estimate volume is some measure of form. In the previous section, a comparison was made between two sample trees and their volumes. These differences, as can be seen by their respective stem analysis graphs (Figures IV-1 and IV-3), were primarily due to a difference in their stem forms.

There are various ways to measure form.

The comparisons of tree bole forms with various solids of revolution may be expressed in numerical terms as form factors. Such ratios are derived by dividing stem volume by the volume of a chosen solid. Form factors, however, cannot be computed until essential stem diameters are obtained at various heights. By expressing these diameter height relationships properly by a taper curve, form factors can be computed (Husch, 1963).

Since these diameters could not be obtained from stems in South Vietnam, stem analysis data of equivalent species from Thailand were used. In the analysis, 344 measurements from 60 trees from Thailand were applied to Behre's (1923,1927) hyperbolic taper formula:

$$Y = \frac{X}{\alpha + \beta X}, \text{ or } Y/X = \alpha+\beta X$$

where

$$Y = {}^{d_i}/D$$

$$X = \frac{H_t - h_i}{H_t - 1.5}$$

d_i = diameter at a relative distance X <u>from the tip of the tree</u>

D = diameter at breast height;

H_t = total height:

H_i = height of d_i; and 1.5 = breast height in meters;

α,β = regression parameters to be estimated.

It is possible to compute the volume of a tree based on a taper curve by revolving the equation of the stem curve about the x-axis and integrating for values of X from base to tip. However, rather than doing this for each tree size, corresponding form factors can be computed from the stem curve. Behre (1927) has shown that the absolute form factor, the ratio of stem volume to the volume of a cylinder, can be computed by the following integration:

$$f_a = \int_0^1 y^2 dX = \frac{1}{\beta 3}\left[1-\alpha^2 + 2\alpha \ln\alpha\right]$$

where the symbols are the same as explained above.

In all cases, the y-intercept, α, was not significantly different from zero at a probability level of 0.05. The resulting β estimates and corresponding form factors are denoted in Table IV-2 that follows:

Table IV-2. Diameters and Form Factors for each Class

Size Class	Mean diameter of class (m)	β estimate	Correlation coefficient (√)	Absolute form factor (f_a)
Small	0.650	1.3575	0.99	0.3997
Medium	1.025	1.3235	0.99	0.4313
Large	1.300	1.2692	0.99	0.4891

C. Inventory Total and Merchantable Volumes

Having determined total heights (H_T), inventory merchantable heights (H_M), diameters (D), and form (F_a), it is now possible to estimate inventory total volumes (V_{IT}) and inventory merchantable volumes (V_{IM}) fo each of the diameter size classes using the following relationships:

$$V_{IT} = \frac{D^2 H_T F_a}{4}$$

$$V_{IM} = \frac{D^2 H_M F_a}{4}$$

These values are given in Table IV-3.

Table IV-3. Inventory Total and Merchantable Volumes per Size Class

Size Class	Volumes (M^3) per stem	
	Inventory Total	Inventory merchantable
Small	3.780	1.882
Medium	11.250	6.458
Large	21.579	14.091

Table IV-4. Species Summary Table

Species	Quality Class	Number of Logs	Mean D.B.H. (cm)	Mean Length (m)	Mean Hoppus Volume (m)
Adina	3	9	61.03	5.73	1.1679
Alstonia	3	13	82.27	5.55	2.1039
Anisoptera	2	237	66.41	9.17	2.1368
Bombax	3	8	68.41	6.99	1.7930
Dalbergia	A	146	46.88	5.80	0.7070
Dipterocarpus	2	239	68.10	7.11	1.8257
Hopea	1	97	79.48	9.65	3.2687
Lagerstroemia	2	157	62.04	6.71	1.4470
Pahodia	1	117	64.05	4.83	1.1047
Parinarium	2	17	69.62	7.16	1.7966
Pterocarpus	A	8	82.37	5.06	1.9453
Shorea	2	48	50.50	8.39	1.0941
Sindora	1	10	85.61	7.53	2.9936
Talauma	1	29	71.06	5.54	1.5886
Tarreha	2	9	83.72	11.98	4.7589
Tetrameles	3	10	99.72	6.73	3.6087
All Species	-	1154	64.91	7.31	1.7550

D. Exploitable Merchantable Volume per Stem

The estimation of exploitable merchantable volume for each diameter size class was developed directly from the mill survey where tree-length logs were measured to determine exploitable merchantable lengths, circumferences, and diameters at large and small ends. These statistics are summarized in Tables IV-4 and IV-5.

Table IV-5. Summary by Log Quality Classes

Quality Class	No. of Logs	% of Total Logs	Avg.DBH (cm)	Avg.Length (M)	Avg.Hoppus Volume (M^3)	Total Class Exploitable Volume (M^3)	% of Total Exploitable Volume
A	154	13.3	48.72	5.76	0.7713	118.78	5.9
1	253	21.9	71.62	6.87	2.0645	522.32	25.8
2	707	61.3	65.23	7.88	1.8329	1295.86	64.0
3	40	3.5	79.08	6.17	2.2073	88.29	4.3
All Classes	1154	100.0	64.91	7.31	1.7550	2025.25	100.0

Using these data, an exploitable merchantable volume table for all merchantable species and species groups was attempted. In order to do this, an appropriate model needs to be selected.

Numerous expressions have been developed to express tree volume in terms of diameter, height, and form. Spurr (1952) has explained some of the most important of these and made comparisons of the results. Spurr (1952) also has shown that the total tree volume formulas work very satisfactorily using merchantable heights, particularly using what Husch (1963) calls the combined variable formula.

Two volume models were used to estimate exploitable merchantable volume regression parameters using the method of ordinary least squares:

Diameter-volume equation: $V = aD^b$

Spurr's combined variable equation: $V = a + bD^2H$

where,

V = merchantable volume, in cubic meters

D = diameter at breast height, in meters

H = exploitable merchantable height, in meters

a,b = regression parameters to be estimated.

Spurr's combined variable model consistently resulted in higher correlation coefficients. However, the plots of residuals revealed trends that indicated that the variances were not constant, even within species. These residuals indicated that the variables increased with increasing volumes, which suggested the need to either use weighted least squares or to transform the observations.

A logarithmic transformation resulted in an equalization of the variances and the resulting residual plots revealed no further anomalies. The resulting transformed model was then as follows:

$$\log V = \log a + b \log (D^2H) \text{ or}$$

$$V = aD^{2b}H^b$$

An analysis of covariance among the sixteen species revealed that the species' volume relationships were significantly different from each other, at a test probability level of .05. Nevertheless, the plot of residuals for the equation for all the species grouped together revealed no anomalies and a good fit indicated by its high R^2 value of 0.98 (R = 0.99). The table that follows, Table IV-6, shows the species with their respective exploitable merchantable volume equations.

Since the volume equations for the different species were significantly different from each other, caution should be used, when estimating exploitable merchantable volumes using the overall equation, particularly when the species mix in a given study forest is not consistent with the mix represented by this study.

In order to estimate exploitable merchantable volumes for each diameter size class considered previously, the data were grouped by size class and the following

TABLE IV-6. Exploitable Merchantable Volume Equations

Species	Equations	Correlation Coefficient
Adina	$V = 0.60111\ D^{1.95966}\ H_E^{0.97983}$	0.9798
Alstonia Scholaris	$V = 0.57047\ D^{1.96342}\ H_E^{0.98171}$	0.9783
Anisoptera	$V = 0.55558\ D^{1.82168}\ H_E^{0.91084}$	0.9907
Bombax	$V = 0.54647\ D^{1.92272}\ H_E^{0.96136}$	0.9790
Dalbergia	$V = 0.52789\ D^{1.78062}\ H_E^{0.89031}$	0.9868
Dipterocarpus	$V = 0.56356\ D^{1.87408}\ H_E^{0.93704}$	0.9909
Hopea	$V = 0.56622\ D^{1.86760}\ H_E^{0.93380}$	0.9864
Lagerstroemia	$V = 0.56738\ D^{1.80828}\ H_E^{0.90414}$	0.9901
Pahudia	$V = 0.55783\ D^{1.82208}\ H_E^{0.91104}$	0.9838
Parinarium	$V = 0.56268\ D^{1.86262}\ H_E^{0.93131}$	0.9774
Pterocarpus	$V = 0.51401\ D^{2.12058}\ H_E^{1.06029}$	0.9868
Shorea	$V = 0.54528\ D^{1.73678}\ H_E^{0.86839}$	0.9880
Sindora	$V = 0.67090\ D^{1.72426}\ H_E^{0.86213}$	0.9890
Talauma	$V = 0.57653\ D^{1.92804}\ H_E^{0.96402}$	0.9908
Tarretia	$V = 0.57088\ D^{1.93188}\ H_E^{0.96594}$	0.9861
Tetrameles	$V = 0.59170\ D^{1.91638}\ H_E^{0.95819}$	0.9706
All Species	$V = 0.54997\ D^{1.87534}\ H_E^{0.93767}$	0.9913

statistics were estimated:

Table IV-7. Exploitable Merchantable Volume per Size Class Stem

Size	Mean Class DBH (M)	Exploitable Merchantable Diameters (M)	Heights (M)	Volumes (M^3)
Small	0.65	0.60	8.73	1.61
Medium	1.03	0.96	8.21	3.67
Large	1.30	1.22	6.48	4.61

E. Branch and Total Wood Volume per Stem

Sabhasri, et al. (1968), as mentioned in a previous section, developed a regression equation for estimateing the volume of the branches of some tropical trees. This was the basis for the estimates used for these volumes for each size class. In this manner, total wood volume can be estimated for each size category as the sum of the inventory total volume and the branch volume of each tree. These estimates are denoted in Table IV-8.

Table IV-8. Branch and Total Wood Volume per Size Class Stem

Size Class	Branch Volume (M^3)	Invnetory Total Volume (M^3)	Total Wood Volume (M^3)
Small	1.362	3.780	5.142
Medium	2.419	11.250	13.669
Large	3.251	21.579	24.830

IV. Inventory Estimates for The Inland Forests of South Vietnam

Needless to say, in order to assess the damage to the inland forests of South Vietnam due to military use of herbicides, a general inventory would have been useful. However, since such a inventory was not available for South Vietnam, the estimates just described would serve as a basis for estimating what those inventory values would be.

Forest inventories, if they involve large areas of land, are almost invariably based upon samples of species composition volumes and growing stock per area. The whole inventory is then determined by extending the data from the sample to cover the population being studied, subject to a certain amount of sampling error, which is what inventory designers try to minimize, constrained by the finite resources allocated to the inventory task.

The inventory needed as a basis for herbicide damage assessment required an estimation of the area occupied by each of several forest types and an estimate of the structure of each forest type in terms of merchantable volumes and growing stock as defined for the project. Prior to discussing the methodology used in obtaining these estimates, it would be worthwhile to first discuss some general aspects of stand composition of forests in Southeast Asia.

A. Stand Composition

The original natural forest stands of the inland forest area of South Vietnam were all-aged and multi-storied in structure. Climax forests of the type represented in this area are comprised of species that are tolerant of competition for light, moisture, nutrients, etc. Some trees represent species that ultimately grow to large size and thus can occupy the first story of the forest. This story is commonly referred to as the emergent story. These trees when they grow to large size typically develop large spreading crowns that form umbrellas over the remaining trees in the forest stand. Tropical forests commonly include a great many species of trees but relatively few species are ever represented in the emergent story. While the mix of species varies from place to place it is not uncommon that approximately ten percent of the tree species found in a forest will be represented in the emergent story with varying frequencies. In the natural inland hardwood forests of South Vietnam the majority of tree specimens in the emergent canopy are members of the family Dipterocarpaceae including specimens from such genera as *Shorea*, *Hopea*, *Dipterocarpus* and *Anisoptera*. Other specimens commonly found in the emergent canopy include representatives of the genera Lagerstroemia, Sindora and Pahudia.

The second story, sometimes referred to as the main story, will be occupied by species represented in the emergent story and also by species that never or rarely occur as emergent trees.

The third story or understory is made up of small specimens of the species that occur in the two upper stories but also representatives of species that never achieve great size. Included in this story are species of bamboo and palms as well as woody trees. Below the understory is a layer of brush, herbaceous plants, ferns, smaller bamboos and palms as well as the seedlings of the tree species that make up the other stories.

The species that make up a forest of which composition and structure generally reproduce in large numbers. Growth of the seedlings and saplings making up the regeneration component of the forest is likely to be slow while they remain in the understory. Many of such specimens die while the survivors move from one size class to the next larger size class. When one of the large emergent trees dies, competition is suddenly reduced and representatives of the emergent species resident in the understory at that point begin to grow rapidly and to compete for the space relinquished by the veteran. One or perhaps two trees are ultimately successful in assuming the dominating role.

This form of stand development results in a diameter distribution pattern that is represented by the familiar J-shaped curve. This typical distribution indicates large numbers of small young trees, and progressively fewer of the larger and older trees going up the range of diameter. Figure IV-4 depicts a profile through such a forest. It is important to recognize that in a stable climax forest the J-shaped distribution remains stationary over the years. If all trees grew equally and all survived, the whole curve would slide up the scale. But what actually happens is that as the trees grow in diameter moving up to the next

Figure IV-4

diameter class, some die due to crowding and other natural competitive causes. In the lower diameter classes, more trees die while few die in the upper classes, and these rates are such that the diameter distribution remains relatively constant. In this way the forest structure is sustained in an essentially stable form.

In forestry, it is common to refer to this process of trees moving up through a sequence of diameter classes as ingrowth. The obvious reason for concern about rates of ingrowth is that this determines the supply of species and numbers of trees available for harvest in the future.

One of the important characteristics of a forest is its species composition. In a tropical forest, there may be 100 to 150 species of trees represented on a single hectare. Of these some are present in large numbers, while others are present in small numbers or are very rare. Species may not be uniformly distributed throughout these stands. It is common to find species in clumps or small aggregation Trees of a given species may be all of the same size or may occur in all sizes, or in only certain separated size classes on a small area. It is apparent that if a specie has specimens in all size classes, then as its largest members die, the next largest will take their place and the species will be sustained in that forest. On the other hand, species that are represented in only one size class or in widely separated clas will disappear when those members die and will re-appear only when they are regenerat from seeds moving in from outside of the area. Thus the proportion of the forest in trees of a particular species may fluctuate over time depending on the regularity of the numbers of smaller trees of the species that are present to move up the range of size.

The sort of climax forest just described is commonly referred to as natural forest, virgin forest, primary forest or primeval forest. If such a forest is heavily used by many, its structure and composition may change and the subsequent successional pattern may change. Since the forests of South Vietnam have been used extensively by man, they are not comparable to natural forests in structure and composition. The structure and composition of any particular South Vietnam forest reflects the history of disturbance in terms of type of disturbance and time sequence of disturbance. Since a given area may have been disturbed in a number of different ways and on an irregular time pattern and, since this history differs substantially from place to place, the status of the forests of South Vietnam varies over a broad range of structure and composition.

B. Stratification and Structure

Bearing this variability in mind and the need to reduce the error on the total estimate, subject to the information the study team had available, the following stratification system was adopted:

Forest type stratum

Diameter class substratum

Merchantability of species substratum

The first two were obtained from photographic sample data. For ease and speed, only three size classes were recognized: small, medium and large (Please refer to the section on photointerpretation for further details). Thus, the total forest was stratified into forest types, each forest type was stratified into diameter size categories and each of these strata were further stratified according to the average proportion of species merchantability. Table IV-9 shows the proportion of each, in terms of percent of total number of stems by forest type and by size class.

C. Volume Estimation

In order to estimate the average proportion of species merchantability, the study team had to depend on estimates made for the forests of Cambodia east of the Mekong (Rollet, 1962). Thus, the volume estimates were derived as follows:

Table IV-9. Proportion of Stems in Each Size Class per Forest Type and Average Proportion of Species Merchantability

Size Class / Forest Type	Small	Medium	Large
1	.9466	.0418	.0116
2	.8749	.1236	.0015
2_1	.9473	.0489	.0038
3	.8302	.1607	.0091
3_1	.9469	.0528	.0003
4	.9410	.0506	.0084
4_1	.9091	.0909	.0000
4_2	.8655	.1346	.0000
5	.5356	.3608	.1066
6	.9763	.0201	.0036
7	.9986	.0014	.0000
8	.9883	.0117	.0000
Avg. All Types	.8933	.0968	.0099
Avg. Prop. of Merchantable Species	0.6900	.7700	.6600

$$VT = \sum_{i=1}^{12} \sum_{j=1}^{3} Aa_i n_i s_{ij} v_j$$

$$VM = \sum_{i=1}^{12} \sum_{j=1}^{3} Aa_i n_i s_{ij} m_j v_j$$

where,

A = total area of the inland forests

a_i = proportion of total area in type i

n_i = number of merchantable size trees per hectare in type i

m_j - proportion of merchantable species in size class j

S_{ij} = proportion of trees in size class j in forest type i

V_j = volume per stem in size class j

VT = volume for all species of size greater than 45 cm in DBH, regardless of species merchantability

VM = volume for merchantable species of merchantable size (greater than 45 cm in DBH)

These volume estimates were obtained for total wood content, inventory total volume, inventory merchantable and exploitable merchantable volume. These estimates are presented in Tables IV-10 to IV-16. All the inventory estimates are volumes of stems greater than 45 cm in diameter. Therefore, the estimate of total wood volume must contain one additional element besides the inventory total volume and branch volume, and that is the total volume of trees less than 45 cm in diameter.

D. Total Non-merchantable volume of trees < 45 cm dbh

Data from analysis of biomass plot data from Cambodia plots established in Thailand, plus plots established for the Inland Forest Study Team by the faculty and staff at the College of Forestry of the University of Kasetsart, Bangkok, Thailand were used to arrive at a volume estimate. The plots in Thailand were chosen to represent moist evergreen, dry evergreen, dry dipterocarp, and tropical rain forests. On these 1 hectare plots every tree of 1 inch or larger diameter was identified, tagged, mapped and measured for diameter and height. Analysis of these data gave excellent figures for the most dense parts of these forests for the plots were carefully selected to give that representation. Regional inventory figures for Northeast Thailand were used to provide reduction factors to adjust the biomass plot figures to estimate average rather than maximum volumes. It was not feasible to obtain separate non-merchantable volume estimates for the various micro-types used in the merchantable volume inventory and damage assessment. Rather an average was estimated for all forest types together as follows:

	Tree Diameter Range, cm			
	0-15	15-30	30-45	All
Number of Stems/hectare	400	60	20	480
Stem Volume, M^3/hectare	4	3	10	17

These figures correspond to roughly half the values for the trees below 45 cm diameter in the dense dry evergreen plot in Thailand and one-fourth the component of the moist evergreen plot. However the number of stems in these size classes is approximately equal to the regional inventory average for exploited and unexploited forests in Thailand. Since the inland forest in SVN include forest types most of which are actively exploited ranging from closed forest without brush to open forest with substantial brush and areas of essentially non-forest vegetation, it is considered that the averages given above are appropriate for approximating the volume of sub-merchantable size trees. The total volume of this size material is estimated to be:

$$(17\ M^3/ha)\ (10,390,000\ ha) = 176.63\ \text{million}\ M^3$$

E. Inventory Volume Estimates

The estimates that have been discussed and presented in prior sections form the basis for estimating the inventory volumes presented in Tables IV-11 to IV-16. These volumes are summarized in Table IV-10 that follows:

Table IV-10. Volume Summary

Type of Estimate	Table	Total Volume (M^3)	Volume/ha (M^3/ha)
Total Wood Content	--	565,733,528	54.45
Total Volume - Stems > 45 cm.	XI	389,103,528	37.45
Inventory Total Volume All species, Stem > 45 cm.	XII	299,291,772	28.81
Inv. Total Volume - Merchantable Species	XIII	210,110,448	20.22
Inventory Merch. Volume All species	XIV	158,470,977	15.25
Inventory Merch. Volume Merchantable species	XV	111,281,674	10.71
Exploitable Merch. Volume Merchantable species	XVI	81,727,201	7.87

For comparison with these volume estimates, the reader is referred to Appendix I which reports reference figures from various countries in S. E. Asia.

Table IV-11. Total Volume for Stems >45 cm dbh

Micro-type	% Area in Type	No. of Merch. Size trees/ha.	Volume per Hectare (m^3)	Estimated total Volume in Type (m^3)
1	5.2	1.20	6.87	3,711,724
2	24.4	7.02	43.70	110,786,492
2_1	10.2	3.89	21.92	23,230,378
3	22.4	10.86	72.67	169,199,072
3_1	10.4	4.05	22.67	24,496,295
4	0.7	6.80	39.02	2,837,925
4_1	0.8	3.47	20.53	288,426
4_2	2.3	2.99	18.81	4,495,026
5	2.6	14.26	147.34	39,802,428
6	10.9	1.58	8.51	9,637,660
7	6.9	0.07	0.36	258,088
8	3.3	0.20	1.05	360,014
TOTAL			37.45	389,103,528

Table IV-12. Inventory Total Volumes for All Species

Microtype	% Area in Type	No. Merch. Size trees/ha.	Volume per Hectare	Estimated Total Inventory Volume in Type
1	5.2	1.20	5.16	2,787,010
2	24.4	7.02	33.20	84,178,800
2_1	10.2	3.89	16.39	17,368,000
3	22.4	10.86	55.85	129,975,000
3_1	10.4	4.05	16.93	18,291,700
4	0.7	6.80	29.29	2,130,330
4_1	0.8	3.47	15.47	1,286,100
4_2	2.3	2.99	14.31	3,419,580
5	2.6	14.26	119.39	32,257,700
6	10.9	1.58	6.31	7,147,130
7	6.9	0.07	0.27	190,219
8	3.3	0.20	0.77	265,203
TOTAL			28.81	299,291,772

Table IV-13. Inventory Total Volumes for Merchantable Species

Microtype	% Area in Type	No. of Merch. Size trees/ha.	No. Merch. size Trees of Comm. Species per ha.	Volume per Hectare	Estimated Total Inventory Volume in Type
1	5.2	1.20	0.83	3.57	1,927,680
2	24.4	7.02	4.92	23.27	58,997,100
2_1	10.2	3.89	2.70	11.37	12,054,900
3	22.4	10.86	7.63	39.24	91,317,400
3_1	10.4	4.05	2.81	11.75	12,691,300
4	0.7	6.80	4.72	20.33	1,478,700
4_1	0.8	3.47	2.42	10.79	896,935
4_2	2.3	2.99	2.10	10.05	2,401,710
5	2.6	14.26	10.21	85.45	23,092,600
6	10.9	1.58	1.09	4.35	4,930,610
7	6.9	0.07	0.05	0.19	135,871
8	3.3	0.20	0.14	0.54	185,642
TOTAL				20.22	210,110,448

Table IV-14. Inventory Merchantable Volumes for All Species

Microtype	% Area in Type	No. of Merch. Size trees/ha.	Volume per Hectare	Estimated Total Inventory Merch. Volume in Type
1	5.2	1.20	2.66	1,436,000
2	24.4	7.02	17.31	43,885,300
2_1	10.2	3.89	8.37	8,872,380
3	22.4	10.86	29.63	68,962,300
3_1	10.4	4.05	8.62	9,309,530
4	0.7	6.80	15.07	1,096,000
4_1	0.8	3.47	7.97	662,792
4_2	2.3	2.99	7.47	1,784,960
5	2.6	14.26	68.94	18,623,400
6	10.9	1.58	3.19	3,610,820
7	6.9	0.07	0.13	94,767
8	3.3	0.20	0.39	132,728
TOTAL			15.25	158,470,977

Table IV-15. Inventory Merchantable Volumes for Merchantable Species

Microtype	% Area in Type	No. of Merch. Size trees per ha.	No. Merch. size Trees of Comm. Species per ha.	Volume per Hectare	Estimated Total Inventory Volume in Type
1	5.2	1.20	0.83	1.84	993,234
2	24.4	7.02	4.92	12.13	30,757,200
2_1	10.2	3.89	2.70	5.81	6,158,200
3	22.4	10.86	7.63	20.82	48,451,400
3_1	10.4	4.05	2.81	5.98	6,459,200
4	0.7	6.80	4.72	10.46	760,755
4_1	0.8	3.47	2.42	5.56	462,235
4_2	2.3	2.99	2.10	5.25	1,253,650
5	2.6	14.26	10.21	49.36	13,334,200
6	10.9	1.58	1.09	2.20	2,491,000
7	6.9	0.07	0.05	0.09	67,691
8	3.3	0.20	0.14	0.27	92,909
TOTAL				10.71	111,281,674

Table IV-16. Exploitable Merchantable Volumes for Merchantable Species

Microtype	% Area in Type	No. of Merch. Size trees/ha.	No. Merch. size Trees of Comm. Species per ha.	Exploitable Merch. Volume/ha.	Estimated Exploitable Merch. volume
1	5.2	1.20	.83	1.45	782,685
2	24.4	7.02	4.92	9.33	23,643,700
2_1	10.2	3.89	2.70	4.68	4,958,020
3	22.4	10.86	7.63	15.25	35,496,400
3_1	10.4	4.05	2.81	4.91	5,259,380
4	0.7	6.80	4.72	8.25	600,311
4_1	0.8	3.47	2.42	4.40	365,426
4_2	2.3	2.99	2.10	4.02	959,984
5	2.6	14.26	10.21	27.63	7,464,860
6	10.9	1.58	1.09	1.82	2,063,010
7	6.9	0.07	.05	0.08	55,835
8	3.3	0.20	.14	0.23	77,590
Total				7.87	81,727,201

References Cited

(1) Behre, C. E. 1927.
"Form Class Taper Curves and Volume Tables and Their Application," Journal Agric. Res., 35 (8): 673-744.

(2) Behre, G. H. 1923.
"Preliminary Notes on Studies of Tree Form," Journal of Forestry, 21: 507-511.

(3) Gartner, E. J. G. and Beuschel, G. K. 1963.
Forest Inventory of the Northeastern Region. Report to the Government of Thailand. Food and Agriculture Organizations of the United Nations, Report No. 1692, Rome.

(4) Husch, B. 1963.
Forest Mensuration and Statistics. The Ronald Press Company, New York.

(5) McKinley, T. W., 1957.
The Forests of Free Vietnam, A Preliminary Study for Organization, Protection, Policy and Production USOM/Saigon.

(6) Ralston, R. A. and Tho, D.C. 1970.
The Forestry Sector of the Economy of the Republic of Vietnam, Saigon.

(7) Sabhasri, S., Khemnark, C., Aksornkoae, S., and Ratisoonthorn, P., 1968.
Primary Production in Dry-Evergreen Forest at Sakaerat I. Estimation of Biomass and Distribution Amongst Various Organs, Research Project 27/2, Report No. 1, ASRCT, Bangkok.

(8) Sandrasegaran, K. 1971.

"Height-Diameter-Age Multiple Regression Models for *Rhizophora apiculata* Bl. (Syn. *Rhizophora conjugata* Turn.) in Matang Mangroves, Taiping, West Malaysia," The Malayan Forester, 34 (4): 260-275.

(9) Spurr, S. H. 1952.

Forest Inventory. The Ronald Press Company, New York.

Appendix I

MERCHANTABLE VOLUMES IN FORESTS OF SOUTHEAST ASIA

In the earlier section on the history of forests of South Vietnam the condition of these forests as a result of human activity has been discussed. The definition and measurement of merchantable volume has been presented in the preceding section.

The purpose of this section is to provide reference figures from various countries in S.E. Asia showing the levels of commercial volume present in various tropical hardwood forests.

A. Virgin hardwood forests

In Malaysia, East Kalimantan (East Borneo), and the Philippine Islands there are extensive areas of tropical forests where rainfall ranges from 80-220 inches per year. These are classified as tropical rain forest or tropical moist forest, and in those regions are dominated by Dipterocarp trees, the best known being the"luans" or "Philippine mahoganies" which are mainly of the genus Shorea.

The virgin forests are found in remote areas often where access and living conditions are difficult, so that human activity has been at a low level. Frequently in these areas the virgin forest appears to have survived because the heavy clay soil or high water table present obstacles to the growing of agricultural crops. Because there is a sparse indigenous human population in these forests, little has been disturbed by agricultural clearing.

Certain portions of the virgin forests have been leased by timber companies which harvest the "luan" trees under strict government control. Typically, in current practice, trees of the merchantable species may be cut only when they are 50 centimeters in diameter (dbh) or larger, and a prescribed number of trees per hectare of diameter 35-50 centimeters must be left to provide a new crop. If there is not a sufficient number present in that size range, the balance must be made up by leaving trees of diameter greater than 50 centimeters. Merchantable volume consists in sound wood of merchantable species in trees of diameter 50 centimeters (or other minimum diameter as specified) and larger.

In preparing harvesting plans, the timber volumes on each section of ground are routinely determined by intensive sampling. These volumes are recorded on maps to be used in planning the road network and logging system. The figures given below were obtained either directly from such maps in current (1974) operations or from reliable personnel thoroughly knowledgeable about the volumes in the operations they supervise.

In the Philippine Islands of Mindanao and Luzon the working figures for average merchantable volume in virgin forests are 100-120 m^3/ha and 80 m^3/ha respectively. It should be noted further that in broken terrain, volumes lower than 50-60 m^3/ha are considered economically unfeasible to harvest.

In East Kalimantan (Borneo) are some of the last very extensive areas of virgin forest in Indonesia. Merchantable volumes in the most heavily timbered areas average 80-100 m^3/ha. In medium density areas the volumes average 50-60 m^3/ha while low density areas carry 30-40 m^3/ha. The range in density of merchantable timber is determined not only by the number and size of the trees, but also the species mixture and the amount of defective or rotten wood. In heavily timbered areas the commercial species make up 80% or more of total volume while this drops to 30-40% in the poorer areas. Similarly the percentage of wood that is defective varies considerably, being often high (30%) in the forests on flat, poorly drained low ground.

The timbered areas of virgin forest in one of the best concessions in East Borneo are estimated to average 70 m^3/ha of merchantable volume overall.

Forest inventory data for Malaya north of Singapore were compiled by FAO forestry teams in collaboration with Malayan Forest Service foresters. The data have not been generally released, but the classes of volume used in the inventory are as follows:

Category of volume	Diameter Range 30cms+	Diameter Range 45cms+
Superior	240 m^3/ha	120 m^3/ha
Good	220 m^3/ha	110 m^3/ha
Moderate	160 m^3/ha	80 m^3/ha

These volumes refer to all species, merchantable and nonmerchantable. Supporting data indicate that of the 240 m^3/ha of diameter 30 cms+ in superior forest, approximately 80 m^3/ha is harvested, hence approximately 67% of the volume 45 cms and larger is in trees of merchantable species and quality.

In the Khao Yoi national park in Thailand, a sample area selected for its high density in moist evergreen forest was found to have 61 m^3/ha in merchantable volume of trees 45 cms dbh and larger.

It must be noted that all the figures noted above refer to virgin forest. When forest inventory is conducted, the timber volumes are recorded, for convenience, for small sample areas which altogether make up a substantial fraction of the total area. The merchantable volume in a 0.1 hectare sample plot can be very high or very low depending on the sampling chance that the plot is located in a dense pocket of merchantable timber or in a pocket of small poles of below merchantable size. Typically these forests are far from uniform in the size and density of the timber, but rather are made up of a mosaic of patches of small and large trees. Hence, it is not unusual to find 0.1 hectare sample plots which contain the equivalent of 300 m^3/ha, and others which contain zero merchantable volume. For extensive inventory, as in the current study, it is the overall mean that eventually must be applied to total areas to estimate total merchantable volume.

B. Exploited hardwood forests

A large proportion of the original virgin forests of Southeast Asia have been exploited, and much has been completely cleared for permanent agriculture. For example, the North half of XT quadrangle, in South Vietnam, which was a site of heavy herbicide activity, had the following composition in 1965 (prior to the spray program).

Closed forest	18.5%	
Broken & open forest	7.2%	41.4%
Scattered trees & clumps in brushlands	15.7%	
Single residual trees in abandoned cleared areas	20.8%	
Swamp & wetlands	2.8%	31.2%
Shifting agriculture	7.6%	
Permanent agriculture and villages	20.7%	27.4%
Urban areas and rubber plantations	6.7%	

In South Vietnam, Cambodia and Thailand there are extensive areas of exploited forest which, although it is "closed" has been harvested over the years and generally contains a relatively low volume of merchantable species that are of merchantable size and quality. In the virgin forest in East Borneo it was estimated that the official cutting regulations on number of trees 35-50 cms to be left, would result in merchantable volume of 35 m^3/ha when those trees had all grown above the 50 cm minimum diameter.

The heavy exploitation and overcutting by villagers and loggers in Northeast Thailand have left stands with an average of 26 m^3/ha in the best and 5-15 m^3/ha in the poorer stands that still are not so exploited that they have not passed out of the timber bearing categories. The figures given by Rollet for the secondary forests of the South Vietnam lowlands, which are the surviving forests after exploitation are 8-13 m^3/ha on the average, for merchantable volume.

C. Shifting agriculture clearings

In essence the shifting cultivation totally destroys the forest in this clearing by cutting and burning. The standing wood volume under this practice is reduced to zero except for trees too large or too hard to cut. If such an area is abandoned and left for 20-30 years it can become heavily covered in tree growth of pioneer species, but may be invaded by bamboo and colonized by hardwood trees much more slowly. However, the species of trees that grow in the 20-30 years after clearing are not merchantable for sawlumber generally; they are useful for papermaking but have no merchantable value unless there is a pulp mill or market for pulp in the vicinity. For that reason the shifting agriculture practices can be considered to eliminate merchantable volume from the forest for a considerable period of years, except where a pulpwood market exists.

D. Inventory volumes in extensive areas

In one of the best timber concessions in virgin forest in East Borneo the average merchantable volume is estimated to be 70 m^3/ha within timbered areas, but 50 m^3/ha within the entire concession area, including patches of cultivated land, grass and swamplands, etc. Such examples can be repeated to show that inclusion of low volume and zero volume areas will depress the average merchantable volume per unit area of land base even where dense natural stands are included. While this is an elementary and seemingly obvious fact, it does seem to elude the inexperienced observer. He can see where there are patches or even extensive areas of timber, but is unaccustomed to the process of mentally averaging these together with the areas of brush, bamboo, swamp, etc. which are all included in the statement of total hectares. The reader might find it instructive to apply the merchantable volume figures for exploited forest and shifting cultivation areas to the vegetation type figures for XT quadrangle (given in C above) and then to compute the overall average for the whole land area.

The examples given in this section are intended as background to assist in understanding the volume inventory discussion given in a later section.

V. Damage Assessment

Vulnerability of forest stands to aerial spraying by herbicides

The effect of an aerially applied herbicide upon a forest tree is a function of the susceptibility of the tree, the amount of herbicide received by the tree, and the fraction of the living crown that was impacted by the herbicide.

In forest stands that are essentially single story in structure and openly spaced, most of the trees in the stand would receive the herbicide treatment and most of the crown area would be impacted. This organization and structure is typical of the "foret claire" of Rollet. These forests, variously referred to as "thin" or "open", result in some cased from heavy selective logging or high grading associated with repeated burning. They typically occur, too, on thin soils, or on soils that have been degraded by excessive or too frequent "ray", or great fire damage. In forests such as these, the species that were susceptible to herbicide treatment suffered substantial damage.

The dense forests, i.e., those whose crowns form a closed canopy, present a different vulnerability picture. Where the stand is of sufficient age to have achieved segregation into crown classes, there is a great range in the vulnerability of individual trees. The emergent trees in a multi-species multi-aged stand commonly have their entire crowns exposed to the herbicide treatment and, if they are highly susceptible to the chemical agent used, are extremely vulnerable to damage under the impact of large doses of herbicides. These same trees serve as umbrellas, intercepting the herbicides and protecting the trees in the lower stories of the forest from direct impact of chemicals.

For the purpose of exploring the vulnerability of forests of a multi-layered structure, a mixed deciduous stand in central Thailand was studied. Sample plots have been established by Smitinand and his associates (1968) on the Sakharat experimental forest. All trees on the plots were identified as to species, located geographically in the plots, and measured to determine diameters at breast height, crown diameters and heights. The crown data for a one quarter hectare plot in this stand were studied in detail to determine the extent of crown overlapping and mutual protection afforded by this sort of stand structure. The area of the crown of each tree in the sample plot was determined. In addition, each tree crown area was subdivided into area exposed from above and area protected from above.

This forest was estimated by the Thailand research team to be 80 to 90 years of age. That is to say, the oldest trees in the stand are thought to be that age. Since tropical trees do not exhibit well defined annual rings it was not possible to make precise determinations of the ages of individual trees. It is an all-aged, multi-storied forest, and it exhibits the classical J-shaped diameter distribution typical of all-aged forests. Table V-1 indicates the crown exposure relationships in this stand. It will be noted that the largest crowns in this stand are in the 16 to 17 meter crown diameter class. These do not represent extremely large crowns in terms of the size of emergent trees in very old, multi-species, all-aged stands of the kind that occur occasionally in Vietnam, Cambodia and Thailand.

For the stand under study, all of the trees with crowns that exceeded 8 meters in average diameter were emergent, and 100 percent of their

Table V-1. Crown Characteristics of a Dry Evergreen Forest in Thailand

Range of Crown Diameters (Meters)	Tree Frequency	Number of Trees Exposed	Number of Trees in Class Exposed
1.0 - 1.9	8	1	12.5
2.0 - 2.9	65	14	23.1
3.0 - 3.9	86	31	36.0
4.0 - 4.9	31	12	38.1
5.0 - 5.9	17	10	58.8
6.0 - 6.9	7	4	57.1
7.0 - 7.9	8	7	87.5
8.0 - 8.9	8	8	100.0
9.0 - 9.9	5	5	100.0
10.0 - 10.9	3	3	100.0
11.0 - 11.9	3	3	100.0
12.0 - 12.9	2	2	100.0
13.0 - 13.9	0	0	0
14.0 - 14.9	4	4	100.0
15.0 - 15.9	0	0	0
16.0 - 16.9	1	1	100.0

crowns were exposed from above. This represented approximately 10 percent of the trees in the stand whose crowns had an average diameter of 1 meter or greater. Fifty-eight percent of the trees with crowns 1 meter in average diameter and greater were completely protected by upper canopy specimens and one-third of the trees with crowns of five meters and larger were completely protected. The older the dense forests, the larger are the crowns of the emergent trees and the fewer are the trees that have substantial crown exposure. Young dense stands in the seedling, sapling and pole stages that are more nearly even-aged will have a much larger fraction of the trees in a posture which exposes all or most of their crowns from above which indicates the high vulnerability to herbicide damage of such young forests, assuming all species to be highly susceptible.

Mature, all-aged, multi-species forests of the type just described may be substantially modified through selective harvesting of the larger or more valuable species. This form of economic selection or "high grading" if it is practiced intensively and over a long period of time will result in a much more open stand structure. This is a pattern of forest exploitation that has been common in South Vietnam for a great many years. In such a forest the umbrella effect that is typical of a mature and essentially undisturbed forest would be much less likely to be present.

It should be noted that there is the possibility of drift of herbicide material under the umbrella, whether it is a bamboo cover over very young trees or an emergent cover in old stands. There is no evidence, however, that drift and through-fall were significant factors in herbicide damage to the forests of South Vietnam.

Study of the forests of South Vietnam that were treated with herbicides clearly indicates that, from the standpoint of reduction in growing stock and disruption of the stand development, the impact of herbicide treatment was much more serious on young forests and on badly degraded forests in Rollet's secondary forest category than on older, more mature forests. These latter forests had the stocking densities and structural organization that provided protection against real damage. On the other hand, the loss of standing merchantable volume was greater in the old, mature forests.

An exception to the rule that the younger stands have larger numbers of trees exposed from above is the case of the very young stand that is developing under a relatively temporary stand of bamboo or beneath one of the tall grasses such as Saccharum. Until the trees emerge from these nurse species, they are protected from herbicide exposure by the herbicide resistant monocotyledon. If they have just emerged from this protective cover, however, they are highly vulnerable.

This discussion of the protective effects of dominating trees in forests treated with herbicides suggests that the frequency distribution of dead trees may be abnormally weighted toward large size trees. This circumstance would occur as already noted only for relatively mature stands which have achieved a stand density and differentiation into crown layers that could provide this protective function. As has been noted previously by Rollet (1962a) and further documented in this study, there is little of this type of forest in South Vietnam, rather the forests have been extensively exploited by economic selection and high grading, and affected by fire, and land clearing for agriculture. As a result many of the forests are thin and open or are comprised of more uniform second growth where differentiation into crown classes has not occurred to a great extent. This type of thin or open, uniform forest also occurs on areas of poor or degraded soils. Since much of the forest does not appear to have a structure that would be conducive to protection by layering, particularly protection of trees larger than the minimum merchantable diameter of 45 centimeters, it was necessary to evaluate the size distribution of dead merchantable size trees. The outcome of the evaluation would determine whether it would be necessary to segregate mortality responses by tree size classes or whether valid estimates of damage could be obtained from the total tree distribution.

A special study was conducted to discover the size distribution of dead trees and of all trees. The results established that the dead merchantable size tree distribution is indistinguishable from that of all merchantable size trees. Furthermore, the general open structure of stands with large trees indicates that protection of merchantable size trees by canopy layers is nil and that death of trees is essentially random with respect to size and therefore is more a function of species susceptibility and vigor, thus values could be developed without regard to distributional differences.

Development and results of the damage assessment models

Herbicide impact upon the inland forests took three forms. Where susceptibility, vulnerability and dosage was sufficiently great trees were killed. Where susceptibility, vulnerability and dosage was below the lethal threshold, trees were defoliated temporarily but recovered their photosynthesizing foliage and resumed growth. Where susceptibility, vulnerability and dosage was quite low no appreciable effect occurred and the trees continued to grow. The task of the committee represented by its inland forest study team was to assess herbicide damage within this framework. Prior efforts to assess damage to inland forests had focused upon impact upon commercial forest volume and the inland forest study team directed its attention to this criterion of damage.

Determination of the status of a forested area of the size represented by the forests of South Vietnam is a monumental task. There had been no prior systematic forest inventory which could be used as a baseline for this exercise. The forests of South Vietnam have, however, been documented with aerial photography far more extensively than any comparable tropical forests in the world. Accordingly the inland forest study team had a wealth of information, potentially available to it, that could be used for forest inventory purposes. Since this aerial photographic coverage includes repetitive photography of the same large areas over the course of more than a decade it constituted a very powerful tool for assessing the impact of herbicide damage as well as for the general evaluation of forest structure and organization and changes in that structure and organization over time. The changes that could be evaluated were not only those induced by military herbicide treatment, but also those that were induced by other military actions, non-military forest uses and the interactions among these.

The real nature of the problem of this assessment can be appreciated by noting the following characteristics:

I) The areas of land classified as "forested" in South Vietnam are very extensive

II) the composition and density of the forests in these forested areas is extremely variable. In fact the forest ranges from extensive areas of bamboo, and slash and burn agriculture clearing now covered in scrub and small trees, to densely timbered areas including large trees.

III) in such a mosaic of vegetation total volume is highly variable, and commercial volume even more so. Even if a small amount of good data were available on volume per hectare, it would be hazardous to use it to estimate volumes in such a variable and extensive forested area.

In these circumstances, and independently of problems of security, the most efficient and usual practice in developing a modern forest inventory in the tropics is to rely on aerial photographs to provide the necessary extensive information.

An early decision of the committee was to concentrate its assessment efforts with respect to inland forests upon the land areas of military Region III. This region included the provinces of Bien Hoa, Binh Duong, Binh Long, Binh Tay, Gia Dinh, Hau Nhgia, Long An, Long Khanh, Phuoc Long, Phuoc Tuy and Tay Ninh. The greatest concentrations of military herbicide treatments directed at inland forests were located in this region and it included more than 50 percent of the forest area of South Vietnam.

Analysis of the Problem

The problem is essentially one of evaluating the impact of a great many treatments (military defoliation) imposed upon the forest at intervals over the period of some six years (1965-1971), through a study of the forest shortly after the defoliation treatments were concluded (winter, 1972-73).

Having been satisfied that the protection effects of stand layering is negligible, two approaches to quantifying the damage to the merchantable portion of the South Vietnam inland forest were developed. The first procedure, called the "Loss Model" builds an estimate based upon dead tree count tallies within each forest type over the entire sample area. The second approach, called the "Inventory Model" estimates damage on the basis of a relation between the percent of merchantable trees killed and the number of times an area was sprayed.

The data collection effort of the forestry study team provided information basic to the two independent estimates of the volume loss of wood to commercially acceptable South Vietnamese mills according to current 1972 utilization standards. The results thus reflect the loss of sawlog and veneer log volume of the kind that would be used in 1972 by the lumber and plywood industries of South Vietnam. These two industries represent the present forest products industry of South Vietnam as there are no pulp and paper or fibreboard plants in the country using raw wood resources. The merchantable volume loss estimates do not include losses of forest inventory in the form of fuelwood. This latter category would include trees of noncommercial species, trees of commercial species not of proper size or quality for current use plus segments of currently useable trees which for one reason or another are left behind in commercial harvesting operations. The damage estimate, therefore, is an estimate of the <u>net</u> volume of trees killed by herbicide and standing in the forests in winter 1972-1973. These are the trees that would be acceptable as a source of industrial raw material at a manufacturing plant.

Loss Model

The loss model procedure initally estimates the number of dead merchantable trees in each of twelve forest micro-types defined by the study team. This calculation is based on counts of dead trees on typed 1:5000 scale aerial photograph samples taken of the forest area in Military Region III. In this step it is assumed that the distribution of dead trees and forest types in all of South Vietnam is similar to that in Military Region III.

The estimated number of dead trees in each forest type is segregated into three merchantable tree size classes defined for tree counting purposes as having the following crown diameters.

10 meters $\leq$ small trees $\leq$ 20 meters

20 meters $\leq$ medium trees $\leq$ 30 meters

30 meters $\leq$ large trees

These crown limits were converted to dbh limits by regression relating dbh to crown diameter described elsewhere in the report.

The dbh limits thus determined are (rounded to the nearest 5 cm.):

45 cm $\leq$ small trees $\leq$ 85 cm.

85 cm $\leq$ medium trees $\leq$ 120 cm.

120 cm $\leq$ large trees

The basis for the segregation into these classes is the proportion of trees tallied in each size class in each forest type obtained during the counting procedure.

The tally of dead merchantable size trees in each forest type is adjusted to remove the portion of counted dead trees that are not of commercial species. That is, the dead tree counting procedure listed all dead trees over the minimum size class and hence includes some trees of nonuseable species. The basis for the adjustment was Rollet's (1962b) inventory of Cambodia where all trees in each of the three merchantable size groupings were compared to the number of trees in the second class and better which represent virtually all of the current commercial species base. This procedure assumes that the comparison for Cambodia is adequate for use in South Vietnam. Although there are some species in the first class in Vietnam classed as second class in Cambodia and vice versa, generally, combining the classes leaves little difference. Use of this information, leaves a model estimate in terms of the number of merchantable species dead trees in each of the three merchantable size classes in each forest type.

The estimate is converted to volume by using data gathered in a survey of South Vietnam mill yards. The tree portions reaching the mill were segregated into the appropriate size class and an average Hoppus volume for each class was determined. This was taken to be the volume of a tree in that size class which ultimately reaches the manufacture site.

A detailed mathematical statement of this procedure, the basic input data, and results are presented in Appendix V-1. This model predicts a total volume loss of currently accepted wood to South Vietnamese mills of 1.245 million cubic meters, Hoppus scale.

For computation purposes the OMMA notation in Step 1 of the procedure outlined in Appendix V-1 is unnecessary. It is useful, however, to report dead trees per unit of area where mortality occurs since this provides a figure that is more related to what the casual observer believes he sees when flying over a damaged area. Typically, such observers fail to properly integrate the undamaged areas in with the damaged areas to obtain a true weighted mean impression. Proper integration often yields an overall value much lower than what the observer claims he saw in a limited and often biased sampling of the situation. The OMMA notation places all the data on the basis such an observer feels more comfortable with and then lets the fact that it occurs in both numerator and denominator of the calculations cancel it out.

There is one major limitation to the loss model other than the assumptions already mentioned and random sampling error. This limitation lies in the fact that as the photographs were analyzed for dead trees there was no reference as to whether a particular dead tree was inside a sprayed area or not. That is, an observer cannot tell when observing a photograph whether a given dead tree is in a sprayed area and thus possibly killed by herbicides or whether it occurs in an unsprayed zone where herbicide must be excluded as a possible mortality cause. This problem inadvertently results in dead trees and OMMA hectares outside sprayed zones being included with data from sprayed areas. The analysis treated all mortality as if it occurred within the sprayed areas. This tends to overestimate the herbicide mortality damage by this model procedure.

Inventory Model

The inventory model procedure initially estimates the area in each forest type sprayed at herbicide treatment levels of one, two, three, and four or more sprayings per hectare. The basis for this step is the mission records plus analysis of typed 1:5000 scale photography in

Military Region 3. This step, therefore, assumes that the distribution of the twelve forest types in Military Region 3 and all of South Vietnam are reasonably close.

The estimated area at each treatment level in each forest type is multiplied by the volume per hectare of currently acceptable small, medium and large sized trees. The basis for these volumes are the number of trees per hectare in each forest type as obtained during the tree counting, the proportion of trees in each size class in each forest type determined during the tree counting, the proportion of trees of the second class and better out of all trees from Rollet, and the average delivered volume per tree of each size group as determined from a study of mill log yards in South Vietnam. This step, like the loss model, has in it the assumption that certain of the Cambodian inventory data from Rollet is adequate for use in South Vietnam.

The total volume in each tree size class in each forest type is multiplied by the estimated percent kill by a regression analysis of the mortality response to herbicide spraying of the inland forest of South Vietnam. Development of this regression analysis is outlined in Appendix V-2. A detailed mathematical statement of this procedure, the basic input data, and results are presented in Appendix V-3. This model predicts a total volume loss of currently acceptable wood to South Vietnam mills of .931 million cubic meters, Hoppus scale.

Assessment of natural and other background mortality

As stated previously the loss model includes dead trees counted that were outside the sprayed areas. These dead trees could be considered as background noise mortality unrelated to herbicides. A portion of this background obviously is naturally occurring mortality. Examination of the data records revealed that the frequency of frames counted having zero, one, two, etc., dead trees revealed that a conspicuously large number of frames had five or fewer dead trees. Five or less dead trees per 93.75 hectares of the 60 quadrat sample area is equivalent to about one dead tree per 19 hectares. A check of these frames reveals that these trees were isolated and scattered suggesting that they died naturally. In any forest containing mature trees, such a thin scattering of dead trees can be found.

Obviously other forms of mortality caused by non-herbicide war activities such as bonbing and fire occurred in the sprayed and unsprayed areas and would tend to increase mortality. An estimate of background mortality that might cause overestimation by the loss model can be obtained by considering the percent kill predicted by the mortality response relationship for the unsprayed area. The percent mortality predicted at zero spraying is 4.2% or 4.2 dead merchantable size trees out of every 100 merchantable size trees. Reducing this to account for nonmerchantable species leaves about 2.9 dead merchantable species trees for every 100 merchantable species trees. Further, it is known from the summary of tree counting that there were 5.72 merchantable size trees per hectare which when reduced for nonmerchantable species leaves about 4.0 per hectare. Combining this information it may be determined that the rate of background mortality was about 2.9 dead useable trees per 25 hectares. Since there were 1,080,037 hectares sprayed, this implies about 126,000 dead useable trees attributable to background noise within the sprayed area. Applying an average useable volume per tree of 1.88 M^3 (obtained by dividing the loss model volume by the number of loss model trees giving a weighted average volume per tree) suggests that background mortality noise in terms of useable volume is of the order of 236,000 M^3. The difference between the model estimates is 314,000 M^3. If the background mortality estimate based on the prediction of percent mortality on unsprayed area is sound, then the difference between the models can largely be reconciled.

As a conservative estimate of the damaged net useable volume, the higher value of the loss model will be used, even though it may contain overestimation due to background mortality. It is the judgement of the study team that the range surrounding the value may be .5 to 2.0 million cubic meters.

Comparison of estimated merchantable utilization volume loss to other Volume measures

The damage assessment estimate provided by the models represents the volume of merchantable species trees of merchantable size that could actually be sold to a mill in 1972-73 based upon mill specifications at that time. There is no implication that all of this material could actually be sold if it had been delivered, particularly in the case of species for which supply far exceeded demand. This is the net removable stemwood and implies that some stemwood may remain behind in the forest. Two other estimates of stemwood volume commonly referred to are the total volume of the stem which is usually called an inventory total volume, and the inventory merchantable volume which is a predictor of the net utilizable merchantable or exploitable volume which the damage assessment has addressed.

Although data were not gathered to calculate these two volumes precisely, rough estimates can be obtained using limited information from

special studies and published reports. The basic data required are estimates of the average diameter (breast height), total height, merchantable height, and form factor of the median tree for each size class. These estimates allow a calculation of inventory total and inventory merchantable volumes for the average tree in each size class which may then be substituted into the assessment models to estimate the inventory total volume loss of merchantable size trees of merchantable species and their associated inventory merchantable volume. The procedures used to obtain the estimates of these volumes per tree are outlined in the Inventory Section
The results obtained from the models are:

	million M^3	
	Loss Model	Inventory Model
Inventory Total Volume Loss of merchantable species over 45 cm dbh	3.175	2.435
Inventory Merchantable Volume Loss of merchantable species over 45 cm dbh	1.661	1.292
Exploitable Volume Loss of merchantable species over 45 cm dbh	1.245	.931

It is important to remember that the primary task of the damage assessment team was to estimate the volumes on the last line of the table because this represents an estimate of the volume from these trees which might actually be used by the South Vietnamese industry.

It is interesting to note that the average volume per merchantable species tree on an inventory merchantable volume basis ranges from 1.9 - 2.4 M^3

per tree which is in agreement with a value of 1.97 M^3 per tree obtained from Rollet (1962b) for merchantable species over 40 cm dbh. These figures were described in more detail in an earlier section of this report.

Assessment of damage to non-merchantable wood

Damage to the herbicide treated forests of SVN was not confined to the currently merchantable component. Many trees not useful for lumber and plywood are useful for fuel. The branches and non-merchantable components of merchantable trees are potentially useful as fuel. In addition, trees of less than merchantable size but of merchantable species constitute the growing stock from which the merchantable crop develops. As previously noted, only a small fraction of these small trees in the growing stock can be expected to live to a merchantable size. Nonetheless, they are important components of the forest viewed as a continually productive renewable resource. Non-merchantable trees have other values such as forage for animals, soil builders and aesthetic values.

Damage to these non-merchantable components of the forest is real but it is difficult to evaluate under the conditions of this study. When small trees were killed by herbicides they quickly decompose and were generally replaced by new vegetation in a short period of time. Accordingly, This damage could not be assessed from a study of aerial photographic samples representing the area several years after the herbicide treatment. Nonetheless, some judgment can be made concerning loss of non-merchantable tree components of the forest based upon knowledge of the structure of the forests, the pattern of spray applications and the effect of spraying on merchantable components of the forest. Estimates of damage to these non-merchantable components can be made with far less precision than is the case for the merchantable components.

As indicated, the nonmerchantable volume loss is comprised of several components. One component is the defective chunks and pieces and upper stem wood below minimum acceptable size of merchantable trees. This may be estimated as the difference between the model calculations of inventory merchantable volume and exploitable volume removed of merchantable species.

Another nonmerchantable loss component is the volume associated with nonmerchantable species trees that are above the minimum merchantable size. This can be estimated by removing the species merchantability reduction factors from the models.

A third non-merchantable loss component is the stemwood of all trees that are less than merchantable size. This can be estimated by using biomass data collected in Cambodia and Thailand to give a volume per hectare of this material, assuming a fractional kill to estimate the volume loss per hectare, and applying these figures to the total area sprayed.

These three components combine to yield an estimate of non-merchantable stemwood volume loss. This loss, combined with the estimate of net merchantable loss, yields an estimate of total gross stemwood loss without regard for utility. It is possible to add to the stemwood loss an estimate of crown branchwood loss above merchantable height by assuming that published crown weight-stem weight relations are reasonable approximates to the crown volume-stem volume relations. The combination of total stemwood plus crownwood yields an estimate of woody above ground biomass loss. The details of the procedure are presented in Appendix V-4 and summarized in Table V-2.

Table V-2 indicates a range of 5.6 - 11.9 million cubic meters of non-merchantable loss with the inclusion of crownwood. This compares with a range of 5.1 - 11.2 million cubic meters estimated earlier with less refined data. The inclusion of merchantable wood loss indicates an above ground woody biomass loss of 6.1 - 13.9 million cubic meters with a median of 9.95 million cubic meters. Branchwood in crowns represent about 30 percent of this total loss.

As in the case of merchantable timber damaged, substantial amounts of the nonmerchantable trees were undoubtedly salvaged for fuel. The extent of these salvage operations could not be determined.

The directo-rate of water and forest of SVN reported a damage of fuelwood quality forest material of 7,583,094 steres*. This is roughly the equivalent of 4,550,000 cubic meters. This figure is less than the non-merchantable timber damage estimated by the committee but the committee's volume undoubtedly includes much wood that would not be considered potential fuelwood by the SVN government.

Interaction Between Herbicide Damage
and Bomb and Shell Damage

Most of the areas of the inland forest treated by herbicide were also affected in some degree by damage from bombing and shelling. While it

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*A stere is a measure of stacked roundwood commonly used in Europe. As a method of measuring wood it is comparable to the cord. In general 1 stere = 0.6 cubic meters.

Table V-2. Estimation of Nonmerchantable Volume Losses Million M^3

	Low	Medium	High
Nonmerchantable volume of trees			
≥ 45 cm dbh[1]	.5	1.0	1.5
All nonmerchantable size (<45 cm dbh)			
Stems	3.7	5.5	7.3
Crowns	1.4	2.2	3.1
Total	5.6	8.7	11.9

[1] Includes nonmerchantable species trees of merchantable size plus component of merchantable tree stems not utilized.

was not a responsibility of the Committee to assess this form of damage, it is necessary to consider it since it has confounded the herbicide damage. The Committee has no records of bomb and shell missions. The aerial photography used in the herbicide damage assessment did provide an indication of the extent of damage from these missions. Also, the mill studies conducted for the purpose of determining tree volume criteria developed considerable emperical evidence of bomb and shell fragment damage to otherwise utilizable raw material.

Bombing and shelling as military impacts extended over a considerably longer period than the herbicide treatments. Photographic evidence indicates that as the herbicide treatment was phased out bombing and shelling was greatly increased. This posed the problem of considering the propriety of assigning damage values to merchantable trees killed by herbicide when they were ultimately destroyed by bombing or shelling.

Damage caused by bombing and shelling was of two general kinds. The first type of damage was the destruction of the forest at the point of impact. Aerial photographs indicate that the forest was completely removed in an area around the impact point. All vegetation from large commercial trees to small seedlings and saplings were eliminated in this area. While the Committee had no information on the nature of the various explosives used, it is apparent that the different explosive units affected different size areas. Figure V-1 illustrates a forest not treated with herbicides that was damaged over large areas from a variety of explosive impacts. The forest was photographed immediately after the military action. The photograph also indicates the difference in impact that occurred in secondary forest and in dense forest. Figure V-2 illustrates the appearance of bomb strikes some time after the time of impact. Figure V-3 illustrates bomb damage at sill later stages where the visual evidence of a strike is less obvious. Examination of sequential photography indicates that much bomb and shell damage loses its specific identity fairly soon, although the changes in the structure and character of the forest resulting from these strikes persist for a very long time.

In the northern half of XT quadrangle, 2301 bomb strikes were counted. From this number, ten bomb strikes were randomly selected and measured for both length and width. Results of these measurements are:

				Hectares		
Bomb				Wet		
Strike	Length	Width	Road	Lands	Forest	Total
1	1750	100		17.5		17.5
2	1850	125			23.1	23.1
3	1500	125			18.8	18.8
4	1700	125			21.5	21.5
5	1850	125			23.1	23.1
6	1900	125	1.0		22.8	23.8
7	2350	100			23.5	23.5
8	3250	150			48.8	48.8
9	3350	125			41.9	41.9
10	1900	100			19.0	19.0
			1.0	17.5	242.5	261
		Percent of Total	.38	6.70	92.92	100.00

Figure V-1 Unsprayed forest showing heavy recent bomb damage

Figure V-2 Appearance of older bomb damage

Figure V-3 Appearance of very old bomb strikes

With an average of 24.25 hectares of forest destroyed per bomb strike, a total area for the 2301 strikes is equal to 55799 hectares or 11.2% of the forest area in this half of the XT quadrangle.

It should be noted that this estimate is probably very conservative for the following reasons: 1) Only well defined bomb strikes were counted; 2) 1969 Photos were used and bombing has continued since that time; 3) usual evidence of bomb strikes disappears within about 4 years, thus older bomb strikes would not be identifiable and therefore tallied; 4) artillery shelling was not included in the counts; and 5) complete coverage of the top half of XT on 1969 photos was not available.

A second type of damage due to bombing and shelling is not detectable and measureable from aerial photography. That is damage due to the imbedding of shrapnel fragments in surviving trees surrounding the openings caused by explosives in the forest. These fragments penetrate the forest beyond the periphery of the area of total destruction. Sometimes the damage done to the tree by the impacting metal fragments is suffcient to cause a quick death due to girdling. Much more frequently, the fragments cause damage that is not immediately lethal, but that is sufficient to provide entrance to the spores of destructive fungi. While many of these trees will survive, the quality of the timber will be substantially lowered, causing a reduction in the fraction of merchantable-size trees that are in fact utilizable, and a reduction in the product yield from utilizable trees. The physical presence of the metal fragments in the trees is perhaps the most serious of all of the problems associated with bomb damage. The entrance scars heal and the evidence of the presence of the fragments disappears over time. The logs are then sold to the conversion industries, where they create severe manufacturing problems; production equipment is damaged, yield is reduced, and product quality is impaired. The time required to cope with the fragments during manufacture seriously reduces the daily production rate. All of these factors tend to reduce the price that manufacturers are willing to pay for logs and to increase the price of the finished products on the market. This latter factor plays a substantial part in maintaining a prohibitive lumber price on the local Vietnamese markets. Furthermore, if hostilities abate and SVN is able to participate actively in the international wood market, the country will be substantially handicapped both from the standpoint of the price that can be obtained, and the general acceptability of its product as it attempts to compete with other sources of the same materials.

One of the insidiuous features of this problem is that the fragments will remain until the tree dies or is harvested and marketed. Accordingly, the wood that is added to the tree through new growth is produced on a defective core and is therefore of lower value regardless of its own intrinsic quality. This is a problem that will last long after other war wounds to the forest, including damage induced by herbicide action, have been healed.

A detailed quantitative estimate of the extent of damage due to bombing and shelling could not be determined. Nonetheless, investigations by the Inland Forest Study Team clearly lead to the conclusion that this damage far exceeded any damage that could be attributed to the use of herbicides and that this damage will be much more difficult to deal with in the long run. These conclusions are based not only on detailed study of aerial photographs, but also on observations made during the utilization study and from conversations with Vietnamese foresters, loggers and mill operators. In 1969 the Joint Development Group stated:

" the longe-range effects of defoliation are not fully known. They will certainly include a loss of growth and perhaps a change of composition towards other species which may be more or less valuable. Less doubt exists regarding the effects of bombardment. Shrapnel has become a common ingredient of Vietnamese logs and can seriously lower their value, especially for export.

Since this observation was made, defoliation activities tapered off and were stopped, while bombing and shelling continued. In view of the importance of bombing as a war-caused forest damage, it would have been far more important to study that than to study the herbicide impact. If there is to be any serious effort to rebuild the forests of SVN to provide a resource for domestic use and export, this matter will have to receive attention.

<u>Relative Impacts of Herbicides and Fires in Upland Forests</u>[1]

The widespread occurrence of fire in the defoliated forests of Vietnam has complicated the evaluation of herbicides, both with respect to ecological impact and to damage to economically important species. Since it was not possible to conduct an extensive ground sampling of forest areas affected by both types of disturbance, a summary of comparative ecological interpretations from Vietnam and elsewhere is useful in evaluating data obtained from aerial photos.

Analogies regarding comparative impacts of fire and herbicides can be gained from research in temperate forests. As in Vietnam, herbicides alone cause mortality of sensitive tree species, but do not result in destruction of the overstory forest cover except where there are pure stands of the most sensitive species. In all cases, including tests with low-dioxin Orange, application of the herbicide has not eliminated the tree component, but has modified the pattern of dominance among species. There has been a loss in diversity where highly sensitive species were present, but resistant species have tended to accelerate in growth. Based on incomplete data, increases or decreases in primary production can be anticipated relative to the untreated forests, depending on which species are resistant.

Fire has a very different role from herbicides. Whereas the herbicide tends to damage aerial parts without causing complete mortality, fire has its principal impact at the ground line, where heat is most intense. Fires virtually eliminate all thin-barked species that do not sprout. Forests comprised entirely of thin-barked species such as alders, cherrys, cascara and others, can be expected to die out completely with a hot ground fire. This situation is not unlike the Dipterocarp forests of Vietnam; in fact, this phenomenon is used to advantage by practitioners of swidden agriculture to open up clearings.

The loss by burning of the vertical component of forest structure is contrasted with the comparatively small shift in dominance within a forest treated with herbicides and not burned. Typically, the herbicide-treated forest briefly supports a small number of pioneer herb species and some forest regeneration, both of which tend to be suppressed soon by the recovering overstory. In communities with a prevalent shrubby understory, the shrubs

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[1]We are indebted to Dr. Michael Newton, Associate Professor, Forest Ecology, School of Forestry, Oregon State University, Corvallis, Oregon, for contribution of this section.

make important gains before the overstory closes in. Fire eliminates the tree component altogether except where there are thick-barked species. In the absence of sprouters, the forest successional pattern must begin with a community comprised largely of herbs and tree seedlings. In the absence of a seed source or fire-resistant seed, the recurrence of tree species may be delayed substantially by the competitive ground cover that develops in their absence. There are thus important structural differences in forests after having been subjected to the two types of disturbances. These differences are readily observable for many years afterwards.

The differences observed would possibly be more pronounced in Vietnam than in temperate forests of the Pacific Northwest. The Dipterocarps are largely fire-sensitive, their seed is of transient viability and they do not sprout. The long dry season would enhance the competitive ability of the *Imperata cylindrica* cover that appears to follow fire so that tree species would be largely absent at the time bamboo species became dominant, perhaps three years post-fire. The absence of trees would tend to prolong the dominance of the bamboo until it flowered and subsided in the natural course. The fact that bamboo was not observed as a major component in sprayed and unburned areas near Thien Ngon, and that *Imperata* and bamboo were abundant in adjacent burned areas, is in support of this hypothesis. The presence of bamboo as observed over wide areas from aircraft was generally restricted to areas where the overstory was totally destroyed, suggesting a recent fire history.

In summary, the impact of fires in temperate forests tends to be far more severe than that of herbicides. Limited ground reconnaissance and extensive aerial reconnaissance and photography tend to confirm that this phenomenon also holds in Vietnam. The widespread occurrence of fires in Vietnam following defoliation has almost certainly caused extensive damage beyond that caused by the herbicides. It seems highly probable that the total damage reported as the consequence of defoliation in the upland forest is comprised of a mixture of damage resulting from herbicides and fires, wherein herbicide effects alone may comprise a relatively minor component. It is the contention of the forestry study team that the long term consequences of fire will be far more severe than those of herbicides alone, and that such damage cannot legitimately be charged against defoliation except as it enhanced the opportunities for burning.

APPENDIX V-1

Loss Model Description and Results

Mathematical Development of the Loss Model

1. Estimate of number of dead trees of all species merchantable size in each forest type.

$NALL_i = A * D * Q * P_i \qquad i = 1,....,12$ forest types

$NALL_i$ = Number of dead trees of all species of merchantable size in forest type i.

A = Total inland forest area sprayed; obtained from data bank of mission records.

D = Number of dead trees per hectare on which merchantable size mortality was observed (called OMMA hectares); obtained from tallies of dead trees from types 1:5,000 scale aerial photography.

Q = Fraction of number of hectares on which merchantable size mortality was observed (i.e., OMMA) to number of sprayed hectares.

$$= \frac{\text{Number of OMMA hectares}}{\sum_j \frac{\text{Sampled area, film j}}{\text{Total area, film j}} * \text{area sprayed, film j}}$$

number of OMMA hectares - observed in tallying merchantable size dead trees from 1:5000 scale aerial photography

sampled area, film j - obtained from numbered sampled film frames and frame area total area, film j - obtained from film flight length and width

area sprayed, film j - obtained from data bank of mission records and flight paths of sample film flights.

P_i = proportion of dead trees found in forest type i, obtained from tallies of dead trees from typed 1:5000 scale aerial photography.

2. Estimate of number of dead trees of merchantable species in <u>each</u> merchantable tree size class in each forest type.

$NCOM_{ik} = NALL_i * M_{ik} * S_k$ i = 1,....,12 forest types

k = 1,...., 3 size classes

$NCOM_{ik}$ = Number of dead trees of merchantable species in each merchantable size class k in each forest type i.

M_{ik} = Proportion of counted merchantable size trees in type i in size class k; determined from tallies from typed 1:5000 scale aerial photography.

S_k = Proportion of trees of all species in size class k that are of the second class and better.

3. Estimate of volume loss of currently acceptable wood in each forest type and each tree size class.

$VLOSS_{ik} = NCOM_{ik} * V_k$ i = 1,....,12 forest types

k = 1,....,3 size classes

$VLOSS_{ik}$ = volume loss of currently acceptable wood in size class k in forest type i

V_k = average volume per tree in size class k currently delivered to South Vietnamese mills as determined from the yard study of South Vietnamese mills.

4. Estimate of total volume loss of currently acceptable wood to South Vietnamese mills. Repeat steps 1-3 for all forest types and size classes and sum.

$$\text{Total Volume Loss} = \sum_{i=1}^{12} \sum_{k=1}^{3} VLOSS_{ik} \qquad \begin{array}{l} i = 1,\ldots,12 \text{ forest types} \\ K = 1,\ldots,3 \text{ size classes} \end{array}$$

This procedure was programmed in Fortran IV for the CDC 6400 Computer System. Table V-1 provides the basic input data and Table V-2 provides the output summary.

Table V-1. Basic Data Used in the Loss Model.

1. Total hectares of sprayed inland forest 1,080,037 ha.
2. "OMA" hectares as a fraction of sprayed hectares .73
3. Average number of dead merchantable size 1.205

   (≥10 meter crown, 45 cm. dbh) trees per OMMA hectare
4. For each forest type proportion of dead trees and proportion of trees in each size class

	Proportion of	Proportion of Trees in Size Class		
Forest Type	Dead Trees	Small	Medium	Large
1	.027	.9466	.0418	.0116
2	.302	.8749	.1236	.0015
21	.107	.9473	.0489	.0038
3	.262	.8302	.1607	.0091
31	.124	.9469	.0528	.0003
4	.020	.9410	.0506	.0084
41	.016	.9091	.0909	.0000
42	.054	.8655	.1346	.0000
5	.018	.5326	.3608	.1066
6	.060	.9763	.0201	.0036
7	.006	.9986	.0014	.0000
8	.004	.9883	.0117	.0000

5. Proportion of trees in each size class that are of merchantable species

Small	.69
Medium	.77
Large	.66

6. Merchantable volume of average tree in each size class

Small	1.61 M^3
Medium	3.67 M^3
Large	4.61 M^3

Table V-2. Results of the Loss Model Computations for Merchantible Volume (Hoppus) Damage Assessment in South Vietnam using 1972 utilization standards.

Volume in Cubic Meters

	Dead Merchantable Volume			
Forest Type	Small	Medium	Large	Total
1	26975	3030	905	30910
2	278862	100215	1309	380386
21	106978	14047	1175	122201
3	229566	113037	6892	349495
31	123922	17578	108	141607
4	19863	2717	486	23066
41	15352	3905	0	19256
42	49327	19514	0	68841
5	10118	17436	5547	33101
6	61824	3238	624	65686
7	6324	23	0	6346
8	4172	126	0	4298
Total	933282	294865	17046	1245193

APPENDIX V-2

Mortality Response Relation

Introduction

Establishment of a relationship between the mortality response of merchantable size trees to intensity of aerial herbicide application is an important consideration in evaluating the damage to the commercial resource of the inland forest of South Vietnam. A merchantable size tree is defined as having a crown diameter of 10 meters which corresponds to a dbh of about 45 centimeters. This was approximately the smallest tree size encountered during a survey of South Vietnam mills in 1972. Mortality was evaluated through use of aerial photographs. Herbicide spraying intensity is defined in terms of the frequency of spraying per hectare flown by military missions during the Vietnam war. Herbicides were sprayed over large areas of inland forest during the years of 1962 to 1971; the heaviest herbicide operations were conducted between 1967 and 1970. Table 1 summarizes data on the herbicides used, their formulation, and the amount of each used during the war.

Literature Review

Fryer and Evans (1970) indicate that the relationship between percent plant response and herbicide dosage is a sigmoid form (Figure 1a). At dosages less than some threshhold value, the herbicide is too weak to elicit a significant plant response. With further dosage increments, plant response gains are rapid until some point after which diminishing returns begin. Ultimately, a saturation dosage occurs beyond which no further response is possible. The exact course depends on the specific herbicide and vegetation considered and is subject to various environmental and seasonal variations. Tschirley (1968) shows sigmoid forms in the response curves of cucumber to several herbicides. A plot of the data of Baron, Stark, and Schubert (1964) of treatments to eradicate mountain whitehorn (ceanothus cordulatus kell.) competition with 2, 4, 5-T from sugar pine (Pinus lambertiana, Dougl.) and ponderosa pine (Pinus ponderosa, Laws) regeneration reveals a sigmoid relation for the response of mountain whitehorn over the range of treatments but only a portion of a sigmoid response by the pines (Fig. 2). Srevastava (1951) noted sigmoid curves when studying the germination of seeds of 11 species in India to soils treated with a range of dosages of four herbicides. A plot by Bondale and Doulay (1969) of the response of Aristada species in India to various doses of the arsenical herbicide Ansar also reveal a sigmoid form.

The sigmoid form may be observed only when a wide range of dosage levels is tested. This range must be sufficient to include extremely weak dosages where little plant response occurs and dosages at and above the maximum possible response. In addition, the sigmoid form will show clearly only if a sufficient number of dosage levels within this range are tested in order to allow reasonable definition of the trend. Most studies in the literature are of an operational test nature and consequently do not satisfy both of these conditions. They often include just one or sometimes neither of the extreme dosage rates and often test only small numbers of dosage rates within the range of the test. Consequently, only a portion of the sigmoid curve such as Figures 1b-1d is defined. Often the number of observations are too few to allow statistical differentiation of the nonlinear portions of Figures 1b and 1d from a straight line.

Numerous examples from herbicide tests conducted at many locations with diverse vegetation suggest portions of a sigmoid curve when the data is plotted. These sigmoid curve segments are illustrated in Figures 1b-d. The studies of the response of Aristada species in India show a form similar to 1-b when the herbicide Phytar was applied at levels up to 2 kg per hectare according to Bondale and Daulay (1969). A plot of response of trees from a lowland dipterocarp rain forest in Malaya to basal spray and frill injections of 2,4,5-T 10 lb. acid equivalent per gallon, reported by Beveridge (1957) suggests a form similar to Figure 1-b whereas a 1:1 mixture of 2,4,5-T/2,4-D, at 6 lb. acid equivalent per gallon is more suggestive of Figure 1-c. In a test of 18 chemicals on 3 species in a nursery in India reported by Srevastava (1951), there are many cases illustrating each of the segment types. A test of picloram on eucalypt coppice clumps conducted by Bachelard, et al. (1965) and a test of combinations of the herbicides in basal and frill sprayings on a wide variety of species in North Borneo reported by Nicholson (1958) suggest the form of Figure 1-d.

A large study of the effects of herbicides on tropical and sub-tropical woody plants reported by Tschirley and his colleagues (1968, 1970) provides many instances of these sigmoid curve segments when data is plotted. These studies include a wide variety of herbicides, plant species, and environmental conditions. A comprehensive analysis of the effects of herbicides on a tropical dry evergreen jungle in Thailand conducted by Darrow, et al. (1967) provided response information that was further refined by Murray and Vaughan (1969) who determined that for a given spray droplet size the percent response varied approximately with the square of the herbicide rate of application in gallons per acre. They found a similar response for flax and black valentine beans. These analyses suggest a form similar to Figure 1-b.

A statistical analysis of the response of hazel bush (Corylus sp) to 2,4-D and 2,4,5-T at 3 dosage levels, 3 mixture volumes, and five stages of foliar development determined that 2,4-D gave superior response and showed that the response was linearly related to dosage according to Roe and Buckman (1963).

Several tests have been conducted in California where herbicides have been applied in successive years. Bentley (1967) in summarizing brushfield reclamation studies with three herbicides indicated that a single spraying failed to achieve brush control, spraying in the second year yielded a kill of 94% of the plants originally present, and a third spraying eliminated almost all of the original plants. Rapid brush seedling reinvasion of sprayed sites was a major problem in achieving effective control to allow conifer regeneration to become established. A later study by Plumb (1971) using 2,4,-D at 4 and 8 lbs. per acre for three successive years indicated no control of scrub oaks with the first spray, about 25% control with the second spray, and over 90% control with the third spray using 8 lb. per acre at each spraying. The 4 lb. per acre rate produced a lesser response. A plot of these results suggests a curve from similar to Figure 1-b.

Arend (1970), Brady, Peevy, and Burns (1969), Darrow, Trubulet and Bartlett (1967), and Tschirley (1968) investigated the response due to aerial herbicide application and have described numerous environmental and stand structure factors which can affect response. These factors are particularly limiting in attempting to compare the responses of different stands to different herbicides if small plots and few replications are used. It is noteworthy that the relationship derived by Murray and Vaughan for the Thailand jungle response was developed from data from aerial tests on relatively large replicated plots.

It must be emphasized that in most of the cited studies the authors did not intend a statistical analysis of the response dosage relations for each herbicide. Rather, they were comparing operational levels of herbicides to determine superiority for a specific task. It is noteworthy that data from these diverse studies, when plotted, suggest part or all of the sigmoid curve. It is particularly relevant that the analysis of airplane delivered herbicides in Thailand and the multi-year repeat applications in California indicate a curve of the form of Figure 1-b. The results of these studies suggest that a parabolic or logarithmic relationship might be discovered for the response of the Inland Forest of South Vietnam to war related aerial herbicide spraying.

Given sufficient data, several possibilities exist to transform the sigmoid curve or nonlinear portions thereof to a form that can be analyzed by linear regression according to Draper and Smith (1966) and Sokal and Rohlf (1969). Appropriate transforms are the probit, square, and logarithm. As long as the use of resulting prediction equation is confined to the range of the data used to define it, there will be no difficulties with the shapes that these transforming functions may have outside the data range. The analysis and use of the results deal with these curves within limits set by the data and it then becomes a contest to determine by some criterion which form best describes the trend of the data within these limtits.

Method

The mortality response of the Inland Forest of South Vietnam to repeated applications of aerially delivered herbicides was measured by means of evaluation of 1:5000 scale aerial photographs obtained from special sampling flights flown in 1972-73. A computer data bank of the spray mission records containing the date, flight path, length, type, and amount of herbicides was combined with the effective spray swath width of 80 meters reported by Herger (1971) to produce a coded map showing the spray frequency at 1 hectare resolution. The sample photograph flights were located on the spray frequency map and the center of every third photograph frame was precisely located. The scheme of using every third frame was used to avoid frame overlap. The area covered by each frame was about 253 hectares (ca 625 acres). Sixty-three frames were selected as representing a wide range of spray intensity. Several of the frames selected were located in unsprayed regions. The only other criterion affecting frame selection was that the coverage be free from obvious damage from other military activities.

For each of these samples, the photograph was subdivided into a 162 quadrat grid, each quadrat covering 1.56 hectares (ca 3.9 acres). The dominant forest type in each quadrat was noted and one quadrat in each forest type was randomly chosen for a full count of all live merchantable trees. The minimum merchantable size tree was defined by a mill yard study as having dbh of 45 centimeters which was translated as a 10 meter crown diameter. Thus, all trees observed as having a crown diameter of 10 meters or more were tallied as merchantable trees. The average number of live trees per quadrat were estimated as the mean of these forest type live tree tallies each weighted by the area of the forest type present.

The central 60 quadrats covering 93.75 hectares (ca 235 acres) were used to determine the dead tree tally. The number of dead trees above the minimum merchantable size defined earlier was tallied for each quadrat and recorded under the appropriate forest type. The mean dead merchantable tree count for these 60 quadrats, combined with the mean live tree count described earlier, was used to estimate the percent merchantable tree mortality for the frame.

To determine the spray frequency for the frame, a clear plastic template was cut to represent the 60 quadrat frame sample area, scaled to the 1 hectare resolution spray frequency map. The template was centered on the plotted center of the photo frame, the frequencies tallied, and the mean spray frequency per hectare was calculated.

The percent merchantable tree kill and average spray frequency for the 63 samples wery analyzed by linear regression to determine the straight line relationship and the relationship via the logarithmic and square transforms. Since there were several zeros in the data, the logarithmic transforms required coding each data value by adding the constant one.

Results

All three equations were found to be highly significant when compared with the critical F values at the .05α -level. The equations in order of superiority as measured by the percent of variation explained (R^2) are

	Coefficient of Determination R^2	Variance
1. $Y = 4.19359 + 2.16867\ X^2$	.649	109.0892
2. $Y = -1.45524 + 9.88170\ X$	.604	123.8531
3. $\log_{10}(Y + 1) = .32958 + 1.59011 \log_{10}(X+1)$	.521	0.1322

Y = % merchantable stand killed

X average spray frequency per hectare

Equation 1 was selected over the other forms tested because of its better fit for further use in the damage assessment procedures. Figure 3 presents a scattergram of the data, the equations and 95% confidence limits. Confidence limits and predicted values for use in the damage assessment are:

		% Merchantable Tree Kill	
Spray Frequency Per Hectare	Predicted	Upper 95% Confidence Limit	Lower 95% Confidence Limit
1	6.4	9.3	3.5
2	12.9	15.5	10.3
3	23.7	27.1	20.3
4 (4.4)*	46.2	53.0	37.4

*Weighted Average of spray frequency for this class

An alternative method of analysis of the mortality response data is the method of probit analysis in which the herbicide response data may be considered from the bioassay viewpoint. In the situation where percent mortality is measured for batches of subjects treated at different levels of a toxicant, probit analysis is the standard analytical technique. Plotted on a natural scale, the mortality-dosage curve typically is a skew sigmoid form. Conversion of a dosage to a logarithmic scale (base 10) tends to make the curve a nearly symmetrical sigmoid which is closely approximated by the normal distribution. The probit transformation converts the response percentages to normal equivalent deviates and adds 5 to eliminate negative values. A plot of the response in probits against the logarithm of dosage usually reveals a linear form. A detailed account of the theory and procedures of probit analysis may be found in Finney (1952).

The usual procedure in assay work provides for an adjustment for a natural mortality amongst the control subjects. However, in the previously derived relationships no natural mortality adjustments were made, therefore, the analytical procedure was used without this adjustment. For ease of plotting and calculation, all dosage values were coded by the addition of the constant one. The resulting probit equation from the analysis of data is

$P = 3.07 + 1.96 \; Z$ $\qquad$ P = probit of Y, $Z = \log_{10} (X + 1)$

X, Y as previously defined

The calculated Chi-square value for the equation was 67.0 with 61 degrees of freedom which was found to be nonsignificant when compared to chi-square at a critical value ($\alpha = .05$) thus indicating no heterogeneity of departure about the fitted line. A plot of the data, probit regression line, and 95% confidence bands is shown in Figure 4. Figure 5 illustrates the asymptotic features of the probit equation when response in percent is plotted against the logarithm of dosage. Conversion to natural dosage (Figure 6) scale removes the symmetry and results in a markedly skewed sigmoid form. Converting the regression and confidence limits to the original scale, the following mortality percents are indicated at selected spray frequencies.

Spray Frequency	Expected % to Kill	95% Confidence Limits	
		Upper	Lower
1	9.0	12.1	6.6
2	15.9	19.8	12.5
3	22.7	29.1	17.1
≥ 4	30.9	41.3	21.8

These values are slightly higher than mortalities derived from the parabolic equation for the lower spray frequencies and lower for the two higher frequencies. The probit analysis indicates a substantially lower mortality in the highest spray frequency class used. The reason for these differences lies in differences between the two analytical techniques. Probit analysis recognizes differences in the number of subjects per batch and hence yields a weighted regression, whereas simple linear regression using percent mortality does not take this into account. With the number of subjects per batch varying from very few up to 35 trees per hectare, and with most of the samples being at doses of 3 or fewer average sprayings per hectare, the effect of the weighted analysis is to regard the high dosage samples with less emphasis than does the simple linear analysis.

The results of the probit analysis agree reasonably well with the parabolic approximation over the range of data employed. Therefore, the parabolic relationship was retained as the basis for damage assessment.

Discussion

The use of the mean spray frequency as a measure of dosage may be questioned on the grounds that the application rate during the war may have been highly variable. According to Herger (1971), the nominal target application specified by the U.S. Air Force was "a herbicide mission should be flown at a speed of approximately 130 knots and at an altitude of 150 feet with the spray pumps delivering enough herbicide to give a concentration

Table 1 Herbicides and applications used durint the Vietnam War

Agent	Chemical Composition	lb/gallon[1]	Application Rate Gallons per Acre	% of gallonage sprayed during the war	% of area covered during the war
Orange	50:50 mixture of the *n*-butyl esters of 2,4,5-T and 2,4-D	4 lb. 2,4-D 4.6 lb. 2,4,5-T	3	65	65
White	Mixture of 2,4-D and picloram	2 lb. 2,4-D .54 lb. picloram	3	32	33
Blue	Sodium salt of cacodylic acid	3.1 lb. cacodylic acid	3	3	2
Purple[2]	50:30:20 mixture of n-butyl ester of 2,4-D, and n-butyl and isobutyl esters of 2,4,5-T		3	-	-

1 acid equivalent basis

2 agent Purple used only until 1964 when replaced by orange. Amount and area sprayed negligible.

Figure 1 Some Relationships between % Response and Herbicide Dosage

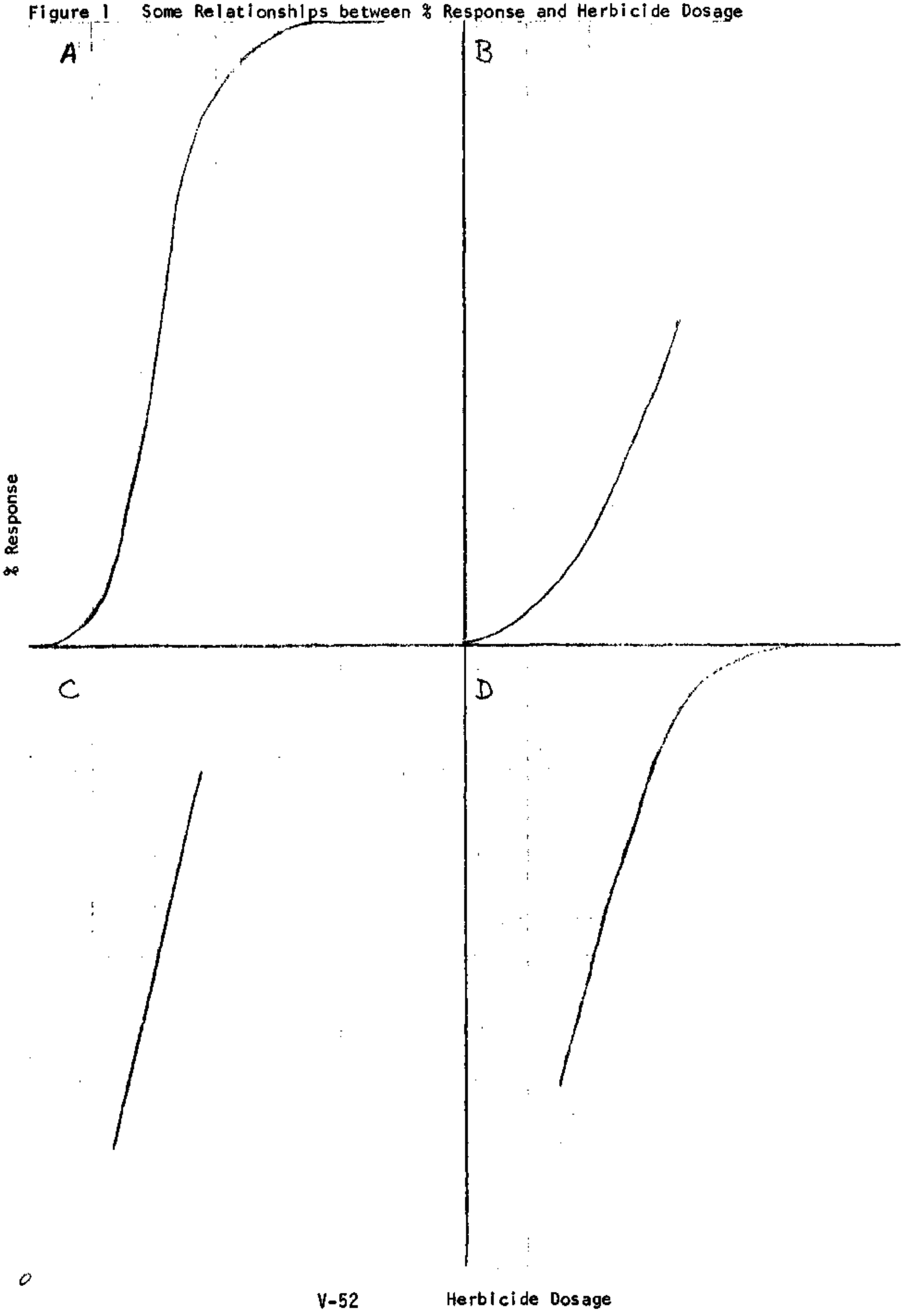

Figure 2 Response of Pinus lambertiana and Ceanothus cordulatus to 2,4,5-T

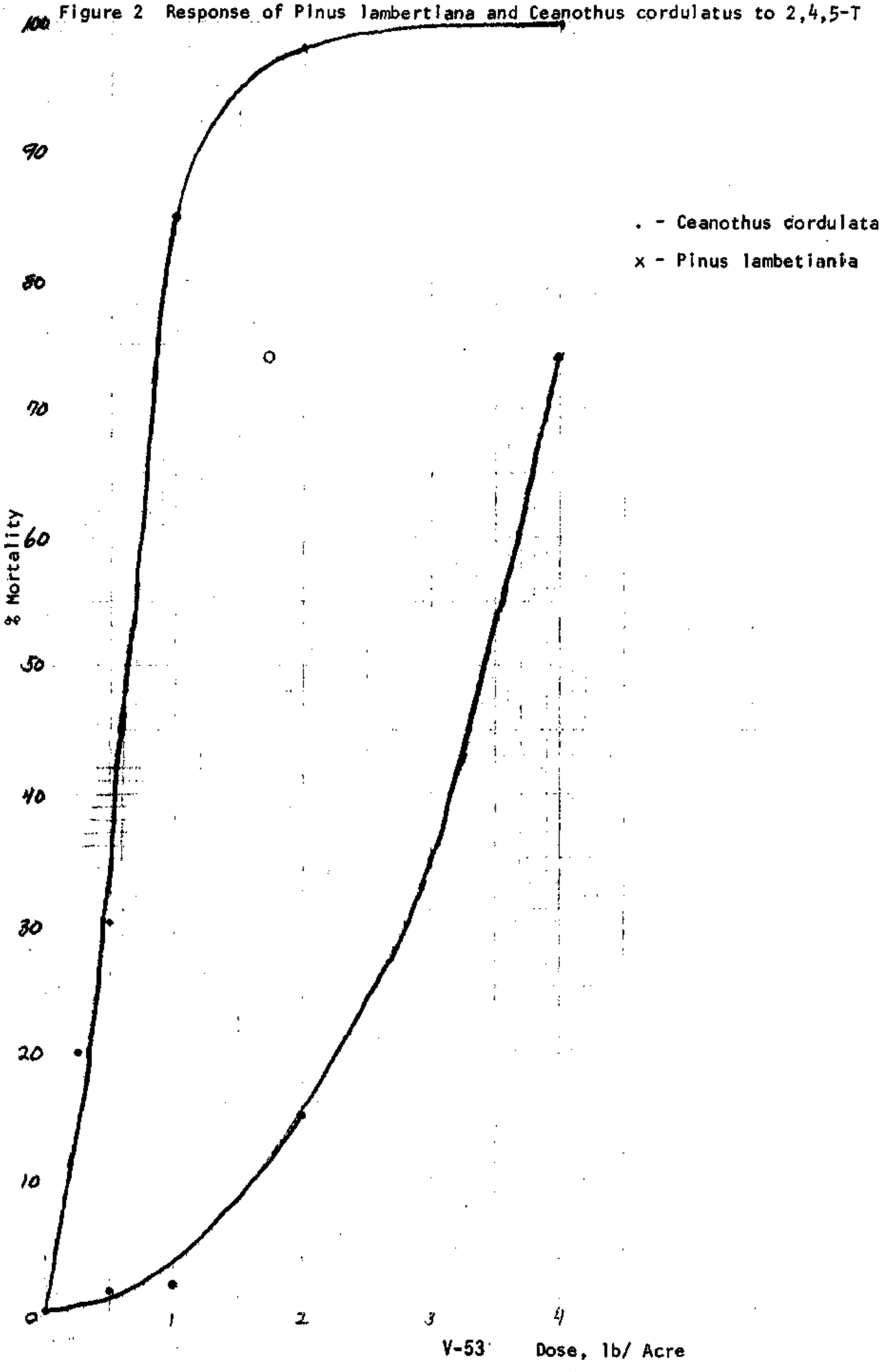

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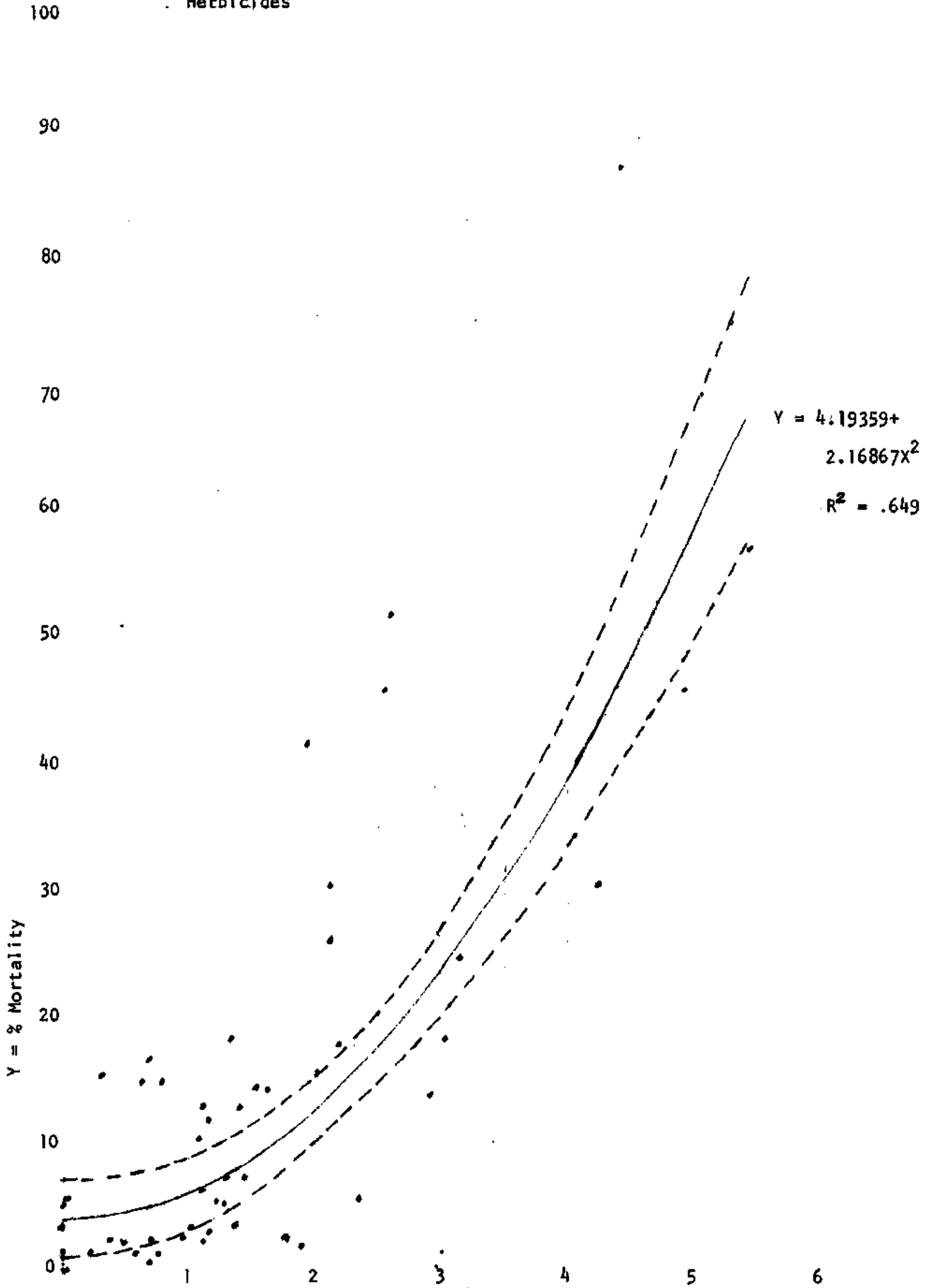
Figure 3 Mortality Response of South Vietnam's Inland Forest to Aerially Released Herbicides



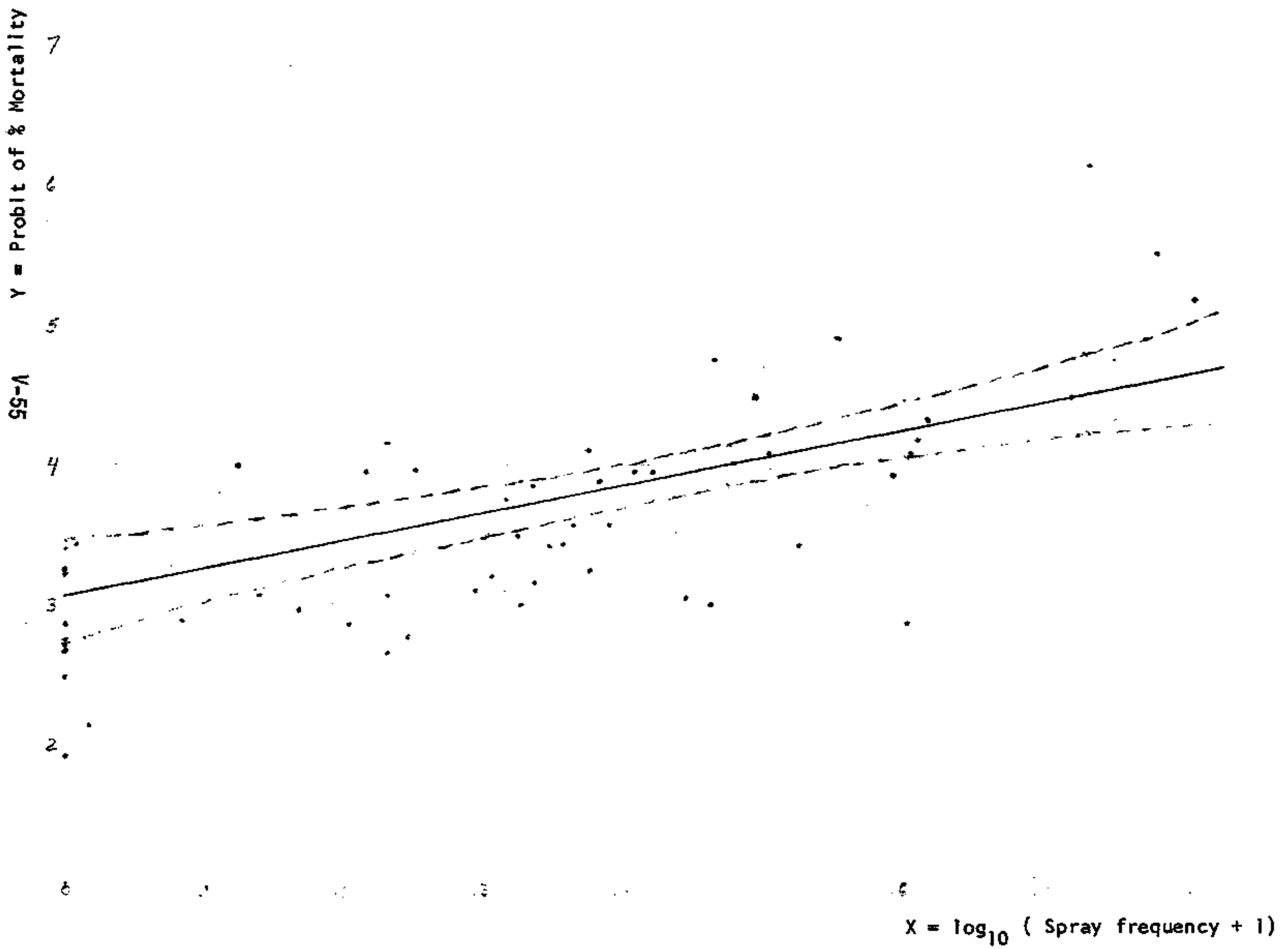


Figure 4 Probit Regression Analysis of Inland Forest Herbicide Mortality

Figure 5 Probit Relation translated to % Mortality, showing Symmetric Sigmoid and Asymptotec Feature or Probit Procedure

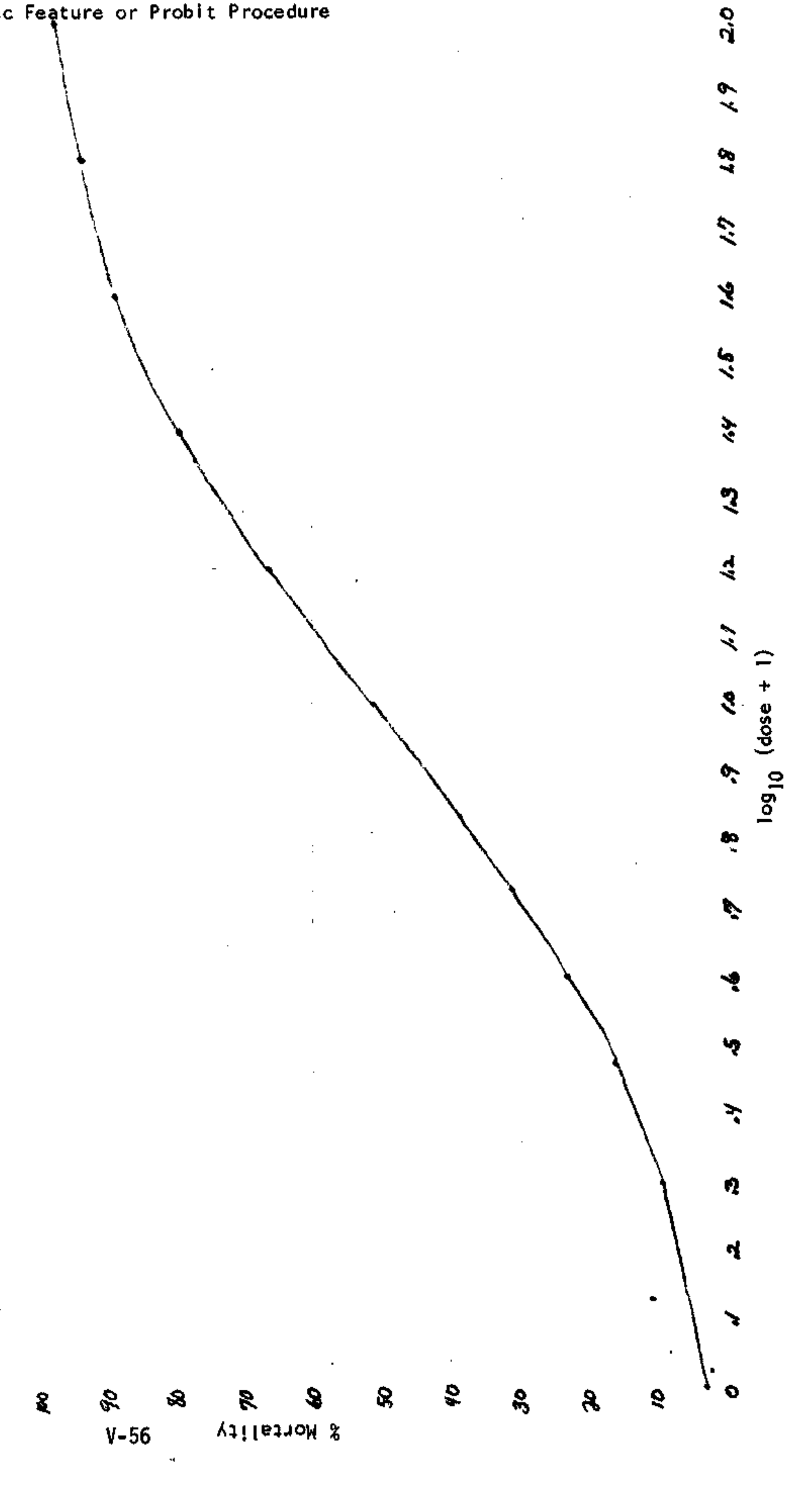
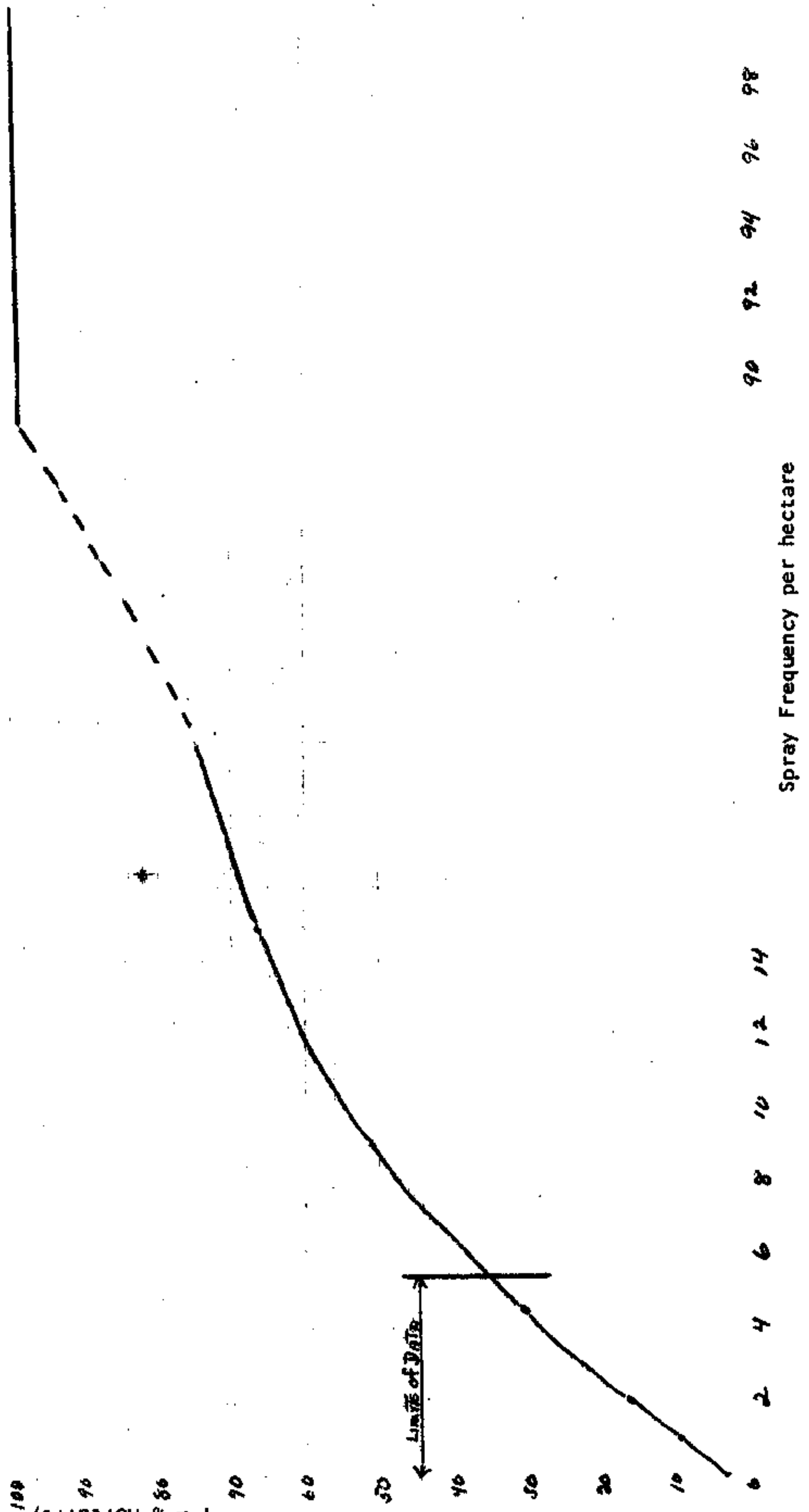


Figure 6 Probit Equation Translated to Natural Scale Illustrating Highly Skewed Sigmoid Form and Limits of Data Used in the Analysis



of 3 gallons per acre." Herger (1971) performed a detailed analysis of 4736 spray mission records which indicated a mean application rate of 3.35 gallons per acre with a standard deviation of .853 gallons per acre.

The mission record data (see table 1) also indicate that about two-thirds of the herbicide applied was agent Orange. At 3 gallons per acre, this is a treatment of 25.8 lbs acid equivalent of herbicide per acre. Nearly all of the remaining herbicide treatment applied was agent White. At 3 gallons per acre this treatment was about 7.6 lb. per acre. It would appear that the use of the number of treatments as a measure of dosage is reasonable in view of the near constancy of the volume rate and the heavy use of these two herbicides. Certainly some of the variability observed in the data may be due to the differences in response to Orange and White or combinations thereof. Another unknown factor contributing to this variability may be the variable timing of the treatments. The military defoliation missions over a specific area often were not timed for a specific interval such as 6-month or annual repetitions. Thus one data value for an area sprayed three times may be the results of three sprayings spaced over six months, another for three sprayings spaced every other year, and another for three sprayings irregularly spaced over some other time interval. It is likely that the measured response would be different under these varied planned and unplanned spray regimes. Certainly the response to repeat sprayings planned and designed to obtain optimum long term defoliation would be different than the response to a similar number of sprayings haphazardly spread over a number of years. This appears to be reflected in the data.

The response of the Inland Forest of South Vietnam to repeated wartime herbicide spraying at about 3 gallons per acre per treatment agrees with the analysis of Murray and Vaughn (1969) of the jungle defoliation tests in Thailand which determined that response varied approximately as the sqaure of gallon dosage applied. These results also seem to agree with the repeat application tests of Bentley (1967) and Plumb (1971) with brushfield and scrub oaks spraying in California.

The range of herbicide treatments measured varies from no spraying to an average of 5.5 sprayings per hectare averaged over a 93.75 hectare sample unit. There were areas which received up to 10 or more sprayings per hectare but there were usually incidental intersections of flight paths and were generally quite small in size. No areas were observed on the spray frequency map with relatively uniform spraying at these high rates that were large enough to be useful samples.

Conclusions

1. Evaluation of vegetation response to herbicides by aerial photograph techniques appears to be a useful method of analysis.

2. The use of spray frequency as a proxy for herbicide dosage is a useful procedure in analysis of repeat spray applications over time with the same or similar herbicides.

3. The response of the Inland Forest of South Vietnam to repeat aerial applications of herbicides used during the war varies as the square of the number of repeat applications over a range from zero to nearly six applications per hectare as measured on sample units of 93.75 hectares.

Literature Cited

Arend, J. L. 1960. Aerial applications for release and conversion in herbicide and their use in forestry, Symposium Proc. Penn. State Univ.

Bachelard, E. G., A. Sarfaty, P. M. Attiwill. 1965. Chemical control of Eucalypt vegetation. Australian Forestry 29(3):181-91.

Baron, F. J., N. Stark, G. H. Schubert. 1964. Effects of season and rate of application of 2,4-D and 2,4,5-T on pine seedlings and Mountain Whitehorn in California. Journal of Forestry 62(7):472-4.

Bentley, J. R. 1967. Brushfield reclamation in California. In herbicides and vegetation management in forests, ranges, and noncrop lands. Proc. Symposium, Oregon State Univ.

Beveridge, A. E. 1957. Arboricide trials in lowland dipterocapr rain forest of Malaya. Malayan Forester 20(4):211-25.

Bondale, K. V., H. S. Daulay. 1969. Efficacy of arsenical herbicides and their doses on the control of Aristada species. Indian Forester 95(6):403-6.

Brady, H. A., F. A. Peevy, P. Y. Burns. 1969. Erratic results from aerial spraying in midsouth hardwoods. Journal of Forestry 67(6):393-6.

Darrow, R. A., G. B. Truchulet, C. M. Bartlett. 1967. Defoliation of tropical dry evergreen forest in Thailand. Dept of the Army, Ft. Detrick, Md. Biological Sciences Laboratory Project ARPA--Order 423.

Dowler, C. C., F. H. Tschirley. 1970. Effect of herbicides on a Puerto Rican rain forest. In Odum, H. T. and R. F. Pigeon. A tropical rain forest, a study of irradiation and ecology at El Verde, Puerto Rico, Div. of Tech.

Draper, N. R., H. Smith. 1966. Applied regression analysis. John Wiley & Sons, New York.

Finney, D. J. 1952. Probit analysis--a statistical treatment of the Sigmoid response curve. 2nd ed. Cambridge.

Fryer, J. D., S. A. Evans. 1970. Weed control handbood: Volume I--Principles British Crop Protection Council, 5th ed. Blackwell Scientific Publications.

Herzer, J. R. 1971. Data quality analysis of the HERB 01 data file. The Mitre Corporation.

Murray, J. A., L. M. Vaughan. 1969. Aerial herbicide applications evaluated for maximum effect and minimum drift. Tech. Report 60, Dept. of the Army.

Nicholson, D. I. 1958. Arboricide trials in north Borneo. Malayan Forester 21(1):17-21.

Plumb, T. R. 1971. Broadcast applications of herbicides to control scrub oak regrowth. USDA Forest Service, Pacific SW Forest and Range Exp. Sta. Research Note PSW-261.

Roe, E. I., R. G. Buchman. 1973. Effect of herbicide dosage and volume on Hazel Bush at different foliar stages. Forest Science 9(4):477-84.

Rollet, B., 1962a. Note sur la vegetation du Vietn-Nam au Sud du 17e parallelle nord (mimeographed). Transl. by Defense Mapping Agency, Topographic Center, Washington, D. C. Nov. 1972.

Rollet, B., 1962b. Report to the Government of Cambodia. Forest Inventory of the East Mekong. Translation by Jose F. Flores (1973).

Sokal, R. R., F. J. Rohlf. 1969. Biometry W. H. Freeman & Co., San Francisco.

Srevastava, T. N. 1951. The application of selective herbicides to forestry practice. Indian Forester 77(3):176-91.

Tschirley, F. H. 1968. Research report . . . Response of tropical and subtropical woody plants to chemical treatments. U. S. Dept. of Agric. Agric. Research Service under ARPA Order 424 U. S. Dept. of Defense.

Appendix V-3

Inventory Model Description and Results

Mathematical Development of the Inventory Model

1. Area in each forest type sprayed one, two, three, and four or more times:

$ATMS_{ij} = A_j * T_i$ $\qquad$ i = 1,....,12 forest types

j = 1,...., 4 herbicide treatment levels

$ATMS_{ij}$ = Area sprayed j times in forest type i

A_j = Area sprayed j times in South Vietnam; obtained from data bank of mission records.

T_i = proportion of area in forest type i; obtained from typed 1;5000 scale and photography.

2. Volume of merchantable species in each merchantable size class sprayed at each treatment level in each forest type.

Merchantable volume per hectare

$$VMRCH_{ijk} = ATMS_{ij} * N_i * M_{ik} * S_k * V_k$$

i=1,...,12 forest types

j=1,..., 4 herbicide treatment levels

k=1,.. , 3 size classes

$VMRCH_{ijk}$ = total volume in forest type i in size class k sprayed j times.

N_i = Number of merchantable size trees of all species per hectare in forest type i; determined from tallies of types 1:5000 scale aerial photography.

M_{ik} = Proportion of counted merchantable size trees in forest type i in size class k; determined from tallies from typed 1:5000 scale aerial photography.

S_k = Proportion of trees of all species in size class k that are of the second class and better.

V_k = Average volume per tree in size class k currently delivered to South Vietnamese mills as determined from the yard study of South Vietnamese mills.

3. Estimate of volume loss of currently acceptable wood in each size class in each forest type at each treatment level.

$VLOSS_{ijk} = VMRCH_{ijk} * B_j$ i = 1,....,12 forest types

J = 1,...., 4 herbicide treatment levels

k = 1,...., 3 size classes

$VLOSS_{ijk}$ = volume loss of currently acceptable wood due to spraying at the j treatment level in tree size k in forest type i.

B_j = Percent kill as determined from regression analysis of samples taken from 1:5000 scale aerial photography.

4. Estimate of total volume loss of currently acceptable wood to South Vietnamese mills. Repeat steps 1-3 for all forest types, treatment levels, and size classes and sum

$$\text{Total Volume Loss} = \sum_{i=1}^{12} \sum_{j=1}^{4} \sum_{k=1}^{3} VLOSS_{ijk}$$

i = 1 ,....,12 forest types

j = 1,...., 4 herbicide treatment levels

k = 1,...., 3 size classes

This procedure was programmed in Fortran IV for the CDC 6400/6500 system. Table 1 provides the basic input data and Table 2 the output summary.

Table 1. Basic Data Used in the Inventory Model

1. Total Hectares of inland forest sprayed at each treatment level

Treatment Level	ha Sprayed
once	694386
two times	251439
three times	90540
four or more times	43672
	1,080,037

2. Proportion killed at each treatment level

Treatment Level	Proportion Killed
once	.064
two times	.129
three times	.237
four or more times	.462

3. For each forest type, the number of merchantable size (≥10 meter crown, 45 cm dbh) trees per hectare

Forest Type	No Merchantable Stems Per ha
1	1.20
2	7.02
21	3.89
3	10.86
31	4.05
4	6.80

41	3.47
42	2.99
5	14.26
6	1.58
7	.07
8	.20

4. For each forest type, proportion of trees in each size class. Sames as the loss model, see Table 1.
5. Proportion of trees in each size class that are of merchantable species. Same as for the loss model, see Table 1.
6. Merchantable volume of average size tree in each size class. Same as for the loss model, see Table 1.

Table 2. Results From Inventory Model Computations for Merchantable Volume (Hoppus) Damage Assessment in South Vietnam using 1972 Utilization Standards

Volume in Cubic Meters

SIZE CLASS = SMALL

APPLIC LEVEL	FOREST TYPE 1	2	21	3	31	4	41	42	5	6	7	8	TOTAL
1	2916	73985	18556	99705	19690	2211	1246	2938	9749	8300	238	322	239858
2	2128	53999	13544	72771	14371	1614	909	2145	7115	6059	174	235	175063
3	1408	35723	8960	48142	9507	1068	602	1419	4707	4008	115	155	115814
4 OR MORE	1324	33590	8425	45267	8939	1004	566	1334	4426	3769	108	146	106897
TOTAL	7776	197296	49485	265885	52508	5897	3322	7836	25997	22136	635	859	639632

SIZE CLASS = MEDIUM

APPLIC LEVEL	FOREST TYPE 1	2	21	3	31	4	41	42	5	6	7	8	TOTAL
1	328	26588	2437	49094	2793	362	317	1162	16800	435	1	10	1[illegible]266
2	239	19405	1778	35832	2038	221	231	848	12261	317	1	7	73180
3	158	12838	1177	23705	1349	146	153	561	8112	210	0	5	48413
4 OR MORE	149	12071	1106	22289	1268	137	144	528	7627	197	0	4	45522
TOTAL	874	70902	6498	130921	7448	807	845	3100	44803	1159	2	26	267381

SIZE CLASS = LARGE

APPLIC LEVEL	FOREST TYPE 1	2	21	3	31	4	41	42	5	6	7	8	TOTAL
1	98	347	204	2993	17	54	0	0	5344	84	0	0	9142
2	71	254	149	2185	12	39	0	0	3900	61	0	0	6672
3	47	168	98	1445	8	26	0	0	2580	40	0	0	4414
4 OR MORE	44	158	93	1359	8	25	0	0	2426	38	0	0	4150
TOTAL	261	926	544	7982	46	144	0	0	14251	224	0	0	24378

SIZE CLASS = ALL

APPLIC LEVEL	FOREST TYPE 1	2	21	3	31	4	41	42	5	6	7	8	TOTAL
1	3342	100920	21197	151792	22500	2568	1563	4101	31892	8819	239	332	349265
2	2439	73658	15471	110788	16422	1874	1141	2993	23277	6437	174	242	254916
3	1613	48729	10235	73292	10864	1240	755	1980	15399	4258	115	160	168641
4 OR MORE	1517	45818	9624	68915	10215	1166	710	1862	14479	4064	108	151	156569
TOTAL	8911	269125	56526	404788	60001	6848	4168	10936	85048	23519	637	885	931391

APPENDIX V-4

Computation of Nonmerchantable Volume Loss

1. Estimate of volumes from the damage assessment models
2. Nonmerchantable volume, trees $\geq$ 45 cm dbh

Defective chunks and subsize upper stem wood from merchantable species

= merchantable species inventory merchantable volume--merchantable species exploitable volume

= 1.661 - 1.245 = .416 - loss model

= 1.292 - .931 = .361 - inventory model

Nonmerchantable species volume

= all species inventory merchantable volume - merchantable species exp oitable volume

= 2.332 - 1.661 = .671 - loss model

= 1.806 - 1.292 = .514 - inventory model

Total

= .416 + .671 = 1.087 loss model

= .361 + .514 = .875 inventory model

Assume Low = 0.5

Medium = 1.0

High = 1.5

3. Nonmerchantable volume, trees <45 cm dbh

The nonmerchantable inventory volume has been estimated as 17 cubic meters per hectare on the basis of biomass and inventory data from Cambodia and Thailand. The inventory on the sprayed area is therefore:

$$17\ m^3/_{ha} \times 1{,}080{,}037\ ha = 18.6\ million\ m^3$$

The amount of this material that would be damaged by herbicide would depend upon a number of factors. In multi-storied forests and particularly in dense multi-storied forests, the trees in the upper stories protect those in lower stories from impact of liquid materials delivered from above.

A study of the overlapping crown structure of a dense forest in Thailand indicated that 56 percent of the trees with a 5 cm dbh and greater were completely covered by understory trees in higher canopies. Seventy-nine percent of the trees had at least half of their crowns covered by over topping trees and 87 percent of the trees showed less than 60 percent exposure.

Semi-dense and open stands would not exhibit the same degree of canopy layering as would be the case in dense stands hence the non-merchantable material in the understory would be more vulnerable to aerial delivery of herbicide. The most vulnerable of the non-merchantable stands were the dense thickets of pioneer species that covered some areas of abandoned swidden. These thickets are made up of fast growing short lived species with very succulent crowns. They are commonly made up of essentially even aged stands with relatively few tree species. In come cases they appeared to behave in response to herbicide treatment much like the mangrove forests. The areas of the inland forests that were cleared of all vegetation in strips similar to the mangrove damage were in this type.

Many areas of abandoned swidden were occupied by grasses and bamboos. The species of trees that make up the mature forest grown under these cover crops and eventually emerge from them to produce a multi-species multi-aged forest. A study was made by Sabhasri and associates at the University of Kasetsart indicated that in many comparable areas in Thailand the tree species emerged from the grass cover in six to twenty-six years after abandonment. Where herbicides were applied before the trees had emerged from the grass or bamboo cover, the resistant cover vegetation protected the tree seedlings. Where the trees had already emerged they were highly vulnerable and mortality was undoubtedly great though this could not be quantitatively determined.

It is probably that the young stands that did not have appreciable quantities of merchantable size trees were more disrupted by the herbicide treatment on a short term basis than were the older dense forests where merchantable timber losses were much higher. It is the judgment of the study team that these losses might ranges from 20 to 40 percent of the total non-merchantable volume on the average over one million hectares, although individual stands could be damaged considerably more or less than this average. At an average spray rate of about 1.8 sprayings per hectare for the million acres sprayed this compares with a predicted percent loss of 11-12 percent from the mortality response curve for merchantable size trees discussed elsewhere in this report.

Applying these kill percents to the total volume of submerchantable material yields the following estimates:

Low	3.7
Medium	5.5
High	7.3

Crowns of merchantable and nonmerchantable species

Crown-stem relations

a. crown weight / stem weight = 39% unweighted by numbers of trees obtained from:

Sabhasri, S. et al. 1968. Primary production in dry evergreen forest at Sakaerat. I-Estimation of biomass and distribution amongst various organs. Report 3, Research Project 27/2. Primary and secondary productivity in tropical dry-evergreen forest. Kasetsart Univ.

b. crown weight/stem weight = 29.4% average of 5 stands types obtained from:

Yoda, Kyoji. 1967. Comparative ecological studies on three main types of forest vegetation in Thailand. III community resperation reprinted from Kire, T. and Ivata, K., nature and life in Southeast Asia. Vol. V. Fauna and Flora Research Society, Kyoto.

c. Considering the data, the average of the five stands appears more appropriate, hence a 30% relation of crownwood to stemwood will be assumed. Generally, the crown wood measure begins at the first line branch which also is often used as an estimate of merchantable height.

To obtain crown volume, assume crown weight/stem weight % and apply to to total stemwood volume (merchantable + nonmerchantable)

	Merch/vol loss		Nonmerch/vol loss				Million m^3
Low	[.5	+	.5	+	3.7]	x .30	= 1.4
Medium	[1.0	+	1.0	+	5.5]	x .30	= 2.2
High	[1.5	+	1.5	+	7.3]	x .30	= 3.1

Summary

	Million m^3		
	Low	Medium	High
Merchantable Stemwood Loss	.5	1.25	2.0
Nonmerchantable Stemwood Loss			
trees ≥ 45 cm	.5	1.0	1.5
trees < 45 cm	3.7	5.5	7.3
Total	4.2	6.5	8.8
Total Stemwood Loss	4.7	7.75	10.8
Crownwood Loss (30% of total stemwood)	1.4	2.2	3.1
Total Above Ground Woody Biomass Loss	6.1	9.95	13.9
Nonmerchantable Wood Loss	5.6	8.70	11.9

VI. Case Study of War Related Impacts

In order to deal in some detail with the effect of herbicides and other factors during the war, a case history covering several years was developed for a selected area which had sufficient sequential photo coverage. The area selected is in the northwest portion of XT at the junction of roads TL/4 and 246 near Katum.

The study considered the developments in three specific sites, one at the intersection of roads TL/4 and 246, and two sites in the valley extending east and north of this road intersection. Figure VI-1 illustrates the location of the roads, the valley, known herbicide missions, and outlines of the study sites. Table VI-1 provides a calendar history of the spray missions. Valley study site 1 has no record of herbicide spraying but does have evidence of some bombing. Valley study site 2 has received both spraying and bombing. Both sites show evidence of human activity believed to be shifting agriculture. The road intersection site received heavy military impact, including construction of a base and airfield, herbicide spraying, bombing and shelling. Figure VI-2 presents the spray hit frequency map for the area.

Although the scale of the photographs varied, the analysis of vegetation changes and, in some cases, documentation of what happened to specific trees was possible. Information concerning the timing of the bomb and spray missions, road and military construction, and vegetation change was obtained from mission records or inferred from interpretation of the photo sequences.

For the purpose of the case study, the following general vegetative classes were defined.

I. Forest

A. At least 30% crown cover by trees. The larger trees have crown diameters of about 10 meters. This corresponds to a dbh[1] of 45 cm and is considered to be the minimum merchantable size in this study. Few trees were found to be much larger than this. Heights and diameters were obtained from measurement of some felled trees in the 1966 photography. These had a height range of 25-35 meters and dbh range of 40-50 cm.

B. Similar to I-A but the trees are more scattered. Ground is generally visible.

C. Forest with no trees of minimum merchantable size

The larger trees in this class are 15-20 meters in height 20-30 cm. dbh, and have crowns about 5 meters in width. These trees could be regarded as pole size and usually were densely stocked in the study sites.

II. Agriculture

Evidence of both currently active and abandoned shifting agriculture.

[1]dhb = diameter breast height = diameter at 1.5 meters.

III. Other Vegetation

Bamboo, brush, young reproduction, etc.

IV. Military Activities

Base and road construction, airports, heliports, etc. directly connected with military operations.

V. Non-vegetative

Rivers, swamps, open areas, bomb craters, villages, roads and other items not included in the other classes.

Road Intersection Study Site

Date	Approximate Scale
Early 1958	1:50,000
April 1966	1:5,000
Feb. 1967	1:7,000
Nov. 1968	1:5,000
June 1969	1:50,000
March 1971	1:40,000

The sample area for each year was located on the 1958 and 1969 1:50,000 scale photography (Figures VI-3 and VI-4). The percent land area in the type categories was determined by the dot count method. This method uses a grid of dots that covers the area. The number of dots in each category divided by the total number of dots yields, in percent, the area covered by each category.

The land utilization for 1958 and 1969 are shown in Table VI-2. Forested area, Category 1, decreased from 63% in 1958 to zero in 1969. The amount of agriculture decreased from 15% in 1958 to zero in 1969. In 1969 62% of the area was bushes, grass and dirt, 30% military activity with the remainder in rivers and roads. This decrease in vegetation may be explained by the resulting analysis of the area over several years. Table VI-3 presents the timing of significant events on the site.

In 1958, the area primarily was agricultural surrounded by forests, with one main road leading to the village site. In 1966, the area was more developed (Figure VI-5). The village centered around the road junction of TL/4 and 246. Several additional roads located to the north of the village suggest increased mobility and, as a result, an increased utility of the land. Several areas were cleared for agriculture since 1958; this is evident in Figure VI-6. Between 1966 and 1967, several events took place, as interpreted from Figure VI-6. First, the area was heavily bombed and burned. Much of the area that was covered with vegetation and forest is bare, or has trees without foliage. It is apparent, however, that agriculture is still practiced in the area north of the village. The disappearance of many large trees is evident. Perhaps the increased activity in 1967 was in preparation of the establishment of a military base in 1968. Between 1967 and 1968, the area was heavily bombed (Figures VI-7 and VI-7a) again, and sprayed with berbicides. The result was the complete removal of the vegetation for some distance from the road junction. An interesting observation is that many of the trees are down, clogging the river, or scattered on the ground. This would suggest some physical damage to the forest that remained from the activity of 1967. In 1969, the area is still primarily a military zone and the vegetation is still being suppressed. In 1971 evidence indicates a relaxation of controlled vegetation practices, however, as trees were seen returning to the edge of the rivers. Small bushes were seen scattered throughout the sample area.

To evaluate the history of individual trees, individuals with crowns in excess of 6 meters, hereafter called "major" trees, were located on the 1966 coverage and, within, the same area, in 1967, and again in 1968. Trees were re-located or noted as missing. The condition of the trees that were physically present was noted. Because of photoscale, individual trees could not be recorded in the 1958 and 1969 coverage.

The number of major trees in 1966 numbered 83 (Figure VI-8). This represented the trees most likely to be identified in later photography, due to location near landmarks, size, or grouping patterns. The 83 trees were all alive, representing 100%. No dead trees were found in 1966, and this date is used as a standard from which to compare later photography. The same area in 1967 (Figure VI-9 had 36 trees that were identified to be the same as on the 1966 photograph. Of the 36 trees, 5 were not defoliated, and 31 were defoliated and presumed dead. It should be remembered that the site was severely bombed between 1966 and 1967. Several of the defoliated trees were located near bomb craters, suggesting that destruction was due to fire or explosion. In fact, of the 31 located trees that were defoliated 10 were located near bomb craters. The area may have been sprayed with herbicides at the same time, accounting for the defoliation of the other 21 trees but the presence of burning over the entire site suggests other possibilities. The evidence in Figure VI-8 suggests that the majority of the located study trees were destroyed by bombing and the resulting fires. Other military operations could have contributed to the damage. It is interesting to note that, of the 21 defoliated trees not close to bomb craters, 15 were close to roads. The remaining 6 defoliated trees and all 5 live trees were some distance from the roads and bomb craters. The evidence thus suggests that a mix of factors, related to military strategy in keeping a devegetated pathway along roads, led to the destruction of many of the study trees.

By 1968, the study site was cleared by a variety of methods for the airbase. The records indicate heavy herbicide application between 1967 and 1968. The five trees that were alive in 1967 were defoliated or on the ground in 1968 (Figure VI-10). In fact, the majority of all trees seen in 1968 were on the ground. The fallen trees were scattered about in a way suggesting they were not being logged. The effect of spraying the area in 1968, or later, would have a minimal effect on trees since virtually all had been destroyed by that time. The herbidide application maps (Figures VI-1 and VI-2) illustrate the spray coverage. The area along the roads 246 and TL/4 was heavily sprayed. The rivers were also sprayed. The effect of the application in 1968, and later, would be to suppress any small vegetation which remained. To provide some insight as to the effect of bombing on the site, bomb craters were measured and the area bombed was determined as a percent of the total site area.

The total area that was hit by bombs in 1967 represents 9% of the area. The bomb crater area in 1968 represents 30% of the site area. Additional disruptions caused by artillery are evident which would increase the total affected area. It appears that no correlation exists between the timing of herbicide application and bombing and the reduction in the tree population. Evidence from the photographs (Figures VI-5, VI-6 and VI-7) indicate that most of the trees were destroyed between 1967 and 1968, in an effort to clear the land in order to establish the base and airfields.

Valley Study Site 1

The dates and scale of photography available for study of the valley sites are:

Date	Scale
Early 1958	1:50,000
April 1966	1: 2,500
Jan. 1968	1: 5,400 (avail. for Site 1 only)
Nov. 1968	1: 3,400
June 1969	1:50,000
March 1971	1:40,000

Table VI-1 and Figures VI-1 and VI-2 indicate that no herbidide spraying occurred in this particular site which covers approximately 50 hectares.

Table VI-4 presents the chronological history of the area from 1958 through 1971. The arrows indicate the approximate timing of significant events such as cutting, bombing, and herbicide missions. The data in the table columns give the percent of area in each of the land categories defined earlier in this section.

The 1958 (Figures VI-3) data indicate that this section of the valley was occupied by a few scattered trees with much young forest growth, brush, bushes, and occasional openings. By April 1966 (Figures VI-11), the area had changed considerably. There is considerable evidence of human activity which probably relates to the developments of access into the valley between 1958 and 1966, as noted in the road intersection site. The reason for the cutting is not clear, but the sub-merchantable size of most of the cut stems (generally less than 30 cm dbh), the haphazard felling, and the presence of dark areas of burned material in the cut area suggest that this is part of the common shifting agriculture practice. In fact, other photography revealed that a large amount of shifting agriculture had been developing in the whole general area around this valley.

Although in April 1966, much of the area had been disturbed by this activity, it was fresh enough to allow reconstruction of what the area looked like prior to the cutting. At that time, perhaps in late 1965, the forest had matured considerably since 1958. This is indicated by the increase in vegetation classes 1-A, 1-B, and 1-C and by the decline in open areas and areas occupied by very young growth.

The April 1966 coverage gives no indication of bombing activity. The mission records (Table VI-1 and Figure VI-1) indicate that no spraying had occurred in this general area. Close examination of the standing forest indicated that type 1-A had 6 live, merchantable-size (crowns 10 or more meters wide) trees per hectare and there were no dead trees in the limited amount of this type available for study. Type 1B had 2.9 live and 0.1 dead mechantable size trees per hectare. There were merchantable-size trees in the other categories, and in the above two types, virtually all the trees measured were barely over the minimum merchantable size.

By January of 1968, or roughly two growing seasons later, the cutover areas were covered with small regrowth, class III. There is also evidence of some bombing. It cannot be ascertained whether the cut material was removed or is merely covered by the new growth. One may speculate that the intensification of the war activities, so well documented in the analysis of the road intersection site, caused abandonment of activities that had been planned after the felling and burning in 1966.

In November of 1968 (Figure VI-12), or another growing season later, the regrowth is even more pronounced. The April 1966 cutover area portrayed in Figure VI-11 is outlined by the dashed line in Figure VI-12. Several large bomb craters are present, most of which occurred after January 1968. Many dead and broken trees are found near the strikes but most are not merchantable in size. All evidence suggests that no herbicide applications reached this portion of the valley. Detailed study of the forest revealed 4.0 live and 1.3 dead merchantable size trees per hectare in type 1-A and 2 live and .4 dead merchantable size trees per hectare in type 1-B. Since herbicide application did not occur, the increased mortality over April 1966 must be attributed to other causes. Since these counts are based on limited area samples in each type, extrapolations to and comparisons with data from other areas would be risky. The figures are useful primarily in indicating the relative change within this site.

The trend among the vegetation classes through 1971 suggests continued regrowth and recovery from the 1966 cutting. At each sample date, there are shifts away from small vegetation and open land categories toward larger sized vegetation.

Valley Study Site 2

This site is located approximately 1 km. east of the intersection of highways 246 and TL/4. Its dimensions are 840 meters x 700 meters, an area equivalent to 58.8 hectares.

This area was subjected to defoliant spray over a span of 3 years. Figures VI-1 and VI-2 and Table VI-1 portray the spray history.

Figures VI-13 and VI-14 show the state of the area for those portions for which there were photographs available in 1966 and 1968. The 1966 portion covers 38 hectares approximately, while the 1968 covers the entire 58.8 hectares of the study area.

The vegetation types used for typing this area were the same as those used for Valley Study Site 1. Table VI-5 shows the estimated proportion of these types as portrayed in the corresponding photographs.

As can be noted in this table, the largest shift in type proportions occurred between 1958 and 1966. This shift occurred mainly in Type 1-A and Type V. Other photographs of areas surrounding study areas 1 and 2 reveal that a major amount of forest clearing was done for purposes of shifting cultivations. Furthermore, the pattern in which the trees were felled, as noted in that portion of 1966 photograph portrayed in Figure VI-13 suggests that they were not felled with logging in mind. In addition, the darker areas of the cleared portion suggest burning, an activity clearly associated with shifting agriculture practices. The shifts in proportion of the Types 1-B and 1-C indicate the maturing trend of these forests as they become better stocked and the remaining trees mature into larger timber.

A somewhat surprising element of these cleared areas is the fact that 2-3 growing seasons later (April, 1966 to November, 1968), no evidence remains of the clearing and felling activities. A viable hypothesis is that the shifting cultivation left the area soon after the clearing and burning took place due to war activities. It was during this period that a military base was established at the road intersection just over 1 km. to the west. The presence of shifting agricultural areas in this region and the selection of these forest types (Types 1-A and 1-B) for their cultivations is not surprising since Rollet reported that, in the East Mekong region of Cambodia, "... The shifting agricultural areas are located essentially in the dense forests and secondary forests."(1) He furthermore asserts that the "abandoned cultivations become covered with thickets and briars"(2) which would account for the increase in Type III, as Type V decreases between 1966 and 1968.

Evidence of Spraying

The 1968 photography revealed that type 1-B was mostly affected by sprays since those areas that provided stereo-pairs showed an average of approximately 3.3 dead merchantable trees per hectare (a total of 50 dead merchantable trees spread over 15.1 hectares). These trees had an average crown size of about 10 meters (i.e., about 45 cm. in diameter). Analysis of the 1966 photography revealed an average of about 8.8 merchantable size trees/ha. for this type. The observed mortality area (OMA) was equal to about 16 hectares for Type B out of a total of 27.5 ha. Hence the OMA proportion is approximately equal to .58 and the number of merchantable dead trees as a proportion of total trees/ha. is approximately .40. The effects of additional spraying missions conducted in 1969 could not be documented due to lack of low level photography over the site following these missions.

(1) Rollet, B. "Report to the Government of Cambodia, Forest Inventory of the East Mekong", FAO Report 1500, Rome, 1962

(2) Idem.

Much of the bombed area in the general region was located outside Study Site 2, but approximately 3.8 hectares within the site showed evidence of bombing. As nearly as could be ascertained, the approximate number of trees that were bombed was equal to about 33 in this area. Since the observed bombed area was primarily in Type 1-B, the average number/ha. of 8.7 reveals a 100% kill in the bombed areas,as could be expected.

Conclusions

These study sites indicate that many processes other than herbicides were also involved in altering the Vietnamese forests during the War period. Damages due to bombing, military construction, and other movement of shifting agriculture are quite significant.

The 1969 photograph (Figure VI-4) sharply delineates the swaths of spray that covered this area, as well as the heavy bombing evidence in portions of the valley. It is interesting to note, however, that no trace of herbicide sprays is evident in the 1971 photograph (Figure VI-15) and that the degree of bombing evidences has been reduced markedly. This great degree of change and recovery occurred over a period of twenty months and indicates the difficulty and complexity in trying to assign damage causes to the Vietnam forests once they have had some time to recover and begin camouflaging original areas.

Table VI-1 Defoliation Missions Within or Near the Study Site

*If mission enters study site

Date	Mission No.	Road Intersection	Valley Site 2	Valley Site 1
66/10/2	496			
66/10/20	923			
66/10/31	487			
66/11/9	922			
66/12/4	469			
66/12/8	910	*		
66/12/9	924			
66/12/9	466	*		
66/12/14	891	*		
66/12/19	456	*		
66/12/23	467			
66/12/29	470	*		
67/1/8	2343	*		
67/1/12	1568	*		
67/1/13	1578			
67/1/20	1127			
67/1/20	1129			
67/1/22	2344	*		
67/1/23	1128	*		
67/1/23	1130			
67/1/24	1137			
67/1/24	1569			
67/2/16	1580			
67/2/20	1577			
67/3/10	1520			
67/4/26	2349			
67/5/11	2351		*	
67/6/25	1572	*		
67/10/28	1579	*		
68/1/19	3119	*		
68/3/20	3736			
68/4/3	3734			
68/4/23	3726	*		
68/4/29	3122	*	*	
68/5/22	3727		*	
68/6/4	3724	*		
68/6/21	3733	*	*	
68/7/2	3120	*		
68/7/14	3121	*		
68/7/30	3730	*		
68/8/9	3116		*	
69/3/8	5720	*	*	
69/4/16	4842	*		
69/5/4	4844	*		
69/5/14	4843			
69/5/26	4850		*	
69/5/27	4845	*	*	
69/6/4	4841			
69/9/4	4851	*	*	
69/10/22	5719	*	*	
69/11/13	4852		*	
69/12/12	4840	*		

Table VI-2

The classification of land use in the 1958 and 1969 areas of the road, as determined by the dot count method.
Intersection Line

Category	1958	1969
I. Forests	63 percent	0 percent
II. Agriculture	16%	0%
III. Other vegetation	16%	62%
IV. Military	0%	30%
V. Other uses	3%	7%

Table VI-3 History of the Road Intersection Site

	1958	1966	1967	1968	1969
Herbicide application	?	none	yes	yes	yes
Bomb strikes	none	none	yes 9% of area in craters	yes* 30% of area in craters	yes*
Other military activity	none	none	airfield base and roads, tracks	base, airfield	base airfield
Other:		road 246			

* indicates new strikes

Table VI-4 % of Area 1 in Begetaion Classes and History of Events, Valley Study Site 1

Vegetation Class	Date / Scale	1958 1:50,000	1966,pre-cut[1] 1:2400	1966,Apr. 1:2400	1968,Jan. 1:5400	1968,Nov. 1:3400	1969,May-June 1:50,000	1971,Mar. 1:40,000
I-A	Fairly dense forest	17.9	40.3	23.5	23.5	23.5	29.0	31.3
I-B	Scattered trees & brush	46.4	29.0	24.9	24.9	24.8	22.6	25.9
I-C	Small trees, pole stands	1.8	13.5	1.6	1.2	1.2	1.6	9.8
III	Brush, bushes, bamboos, saplings	30.3	17.2	17.2	50.3	50.2	46.8	33.0
V	Open	3.6	----	32.8	.1	.3	----	----
Events				↑ cutover	↑ bombing	↑ bombing		

(1) Estimate based on reconstruction from April 1966 coverage.

Table VI-5 Percent of Area in Vegetation Classes, Valley Study Site 1

Vegetation Class	Date / Scale	1958 1:50,000	Pre-1966[1] 1:2400	1966, Apr. 1:2400	1968, Nov. 1:3400	1969 May-June 1:50,000	1971, Mar. 1:40,000
I-A.	Fairly dense forest	21.14	10.10	3.62	----	----	----
I-B.	Scattered trees and brush	41.07	54.98	49.00	46.76	52.38	64.28
I-C.	Small trees, pole stands	14.28	10.89	10.09	13.11	14.28	5.36
III.	Brush, bushes, bamboos, saplings	23.51	24.03	27.94	38.60	30.95	28.57
V.	Open	----	-----	9.35	1.53	2.39	1.79

(1) Estimated from 1966 photographs

Figure VI-1 Study Area Schematic Showing Study Sites and Locations of Herbicide Mission Center Lines

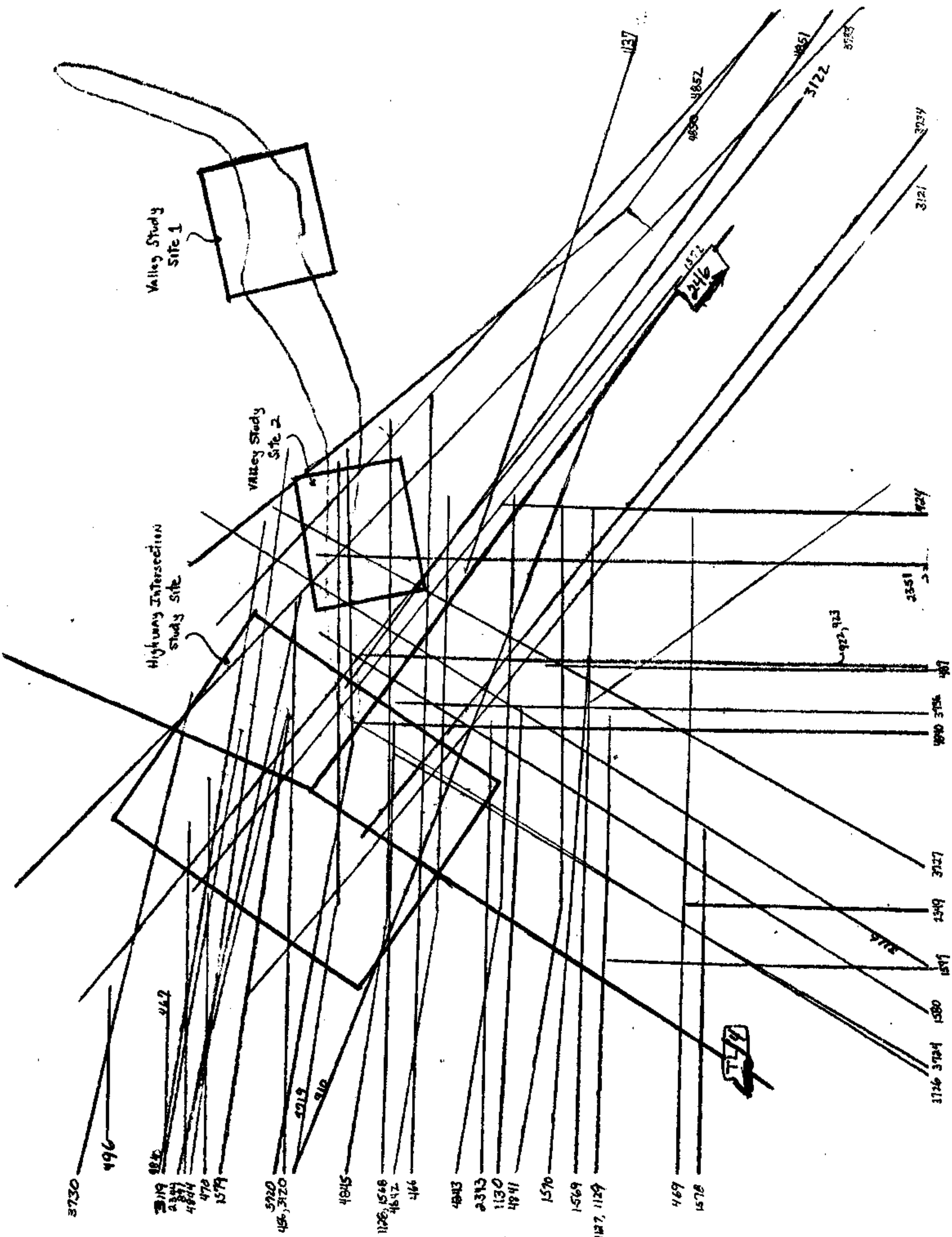
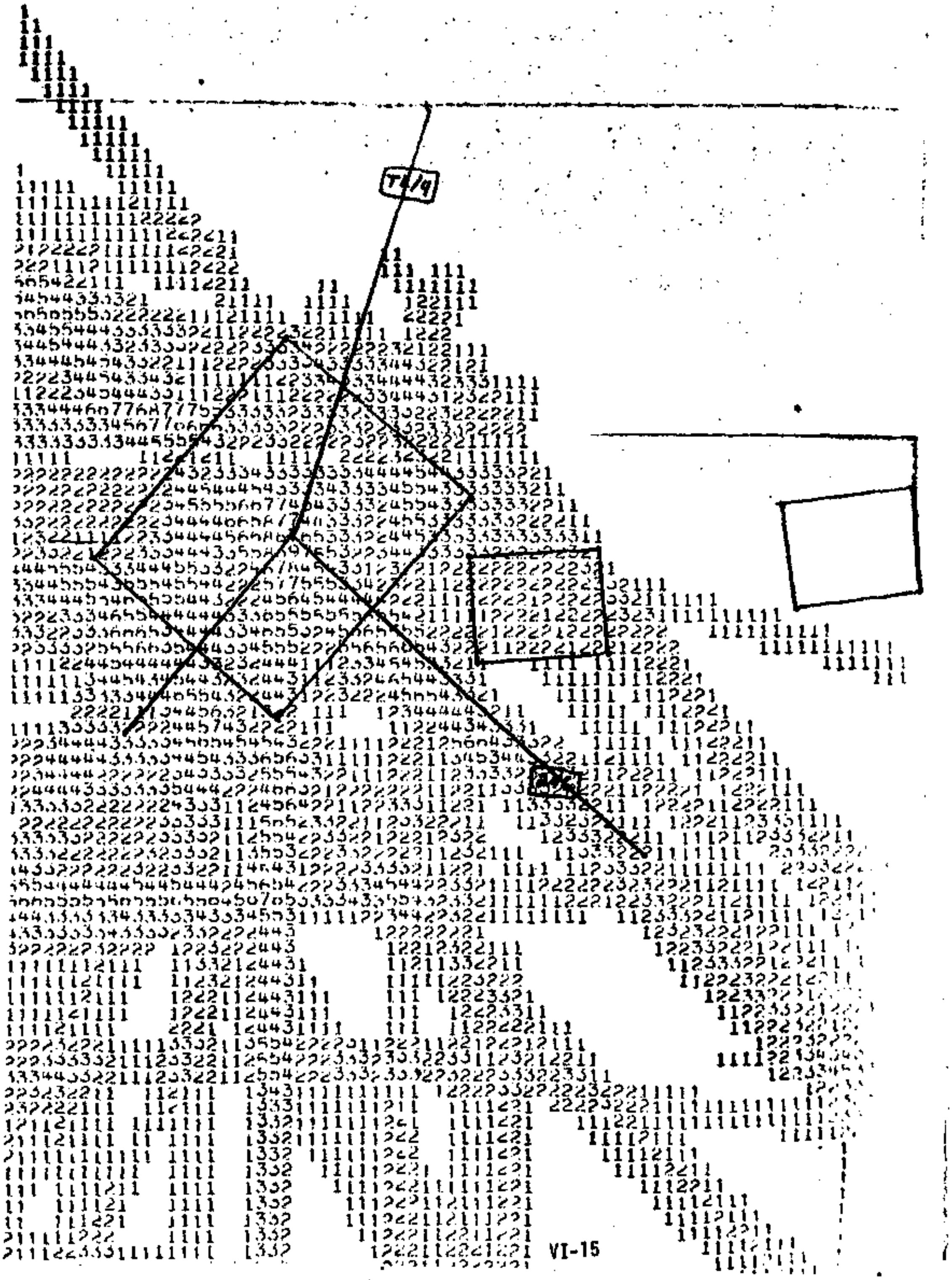


Figure VI-2 Spray Hit Map for the Study Sites



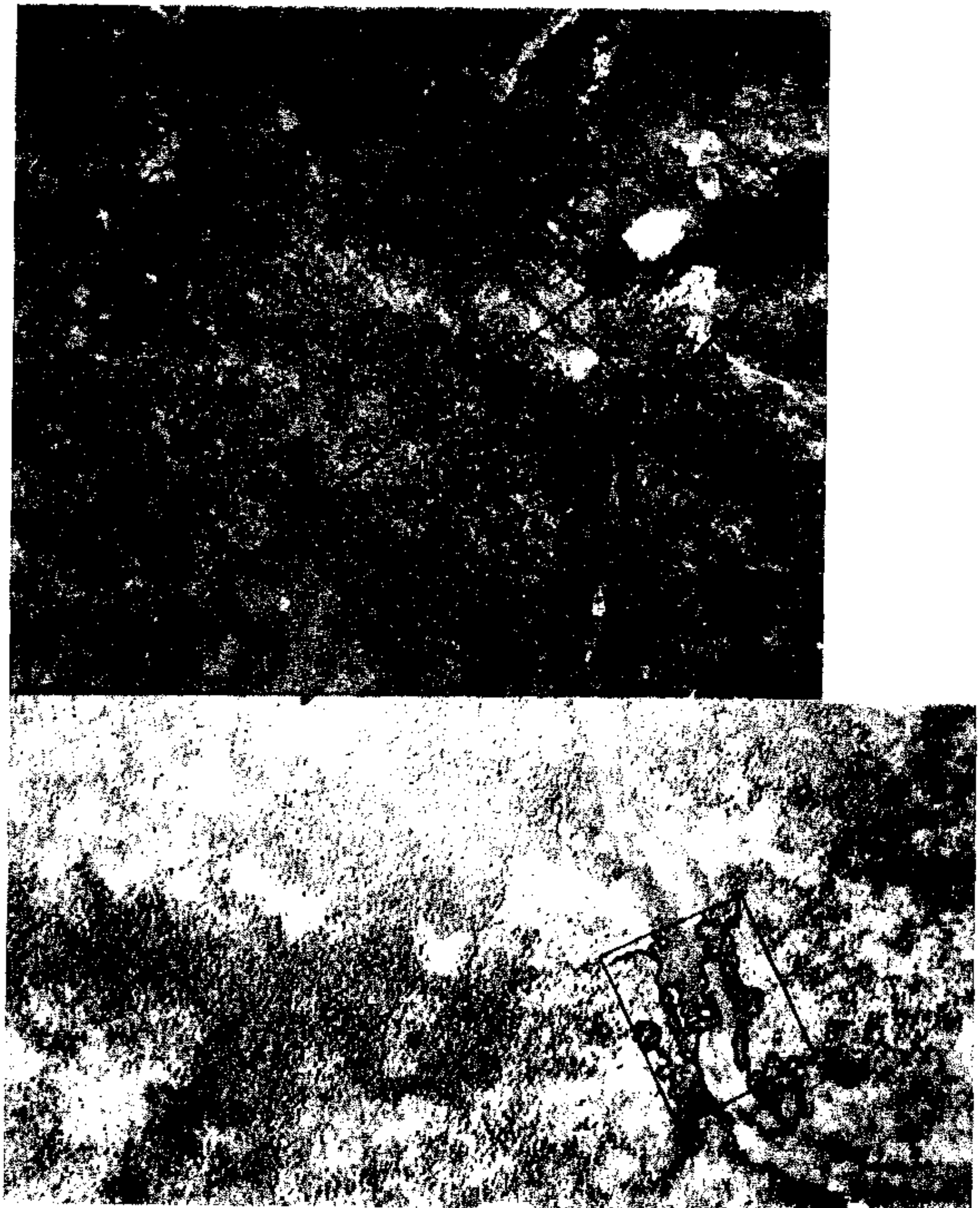


Figure VI-3 1958 1:50,000 Photography of the Study Sites

Figure VI-4 1969 1:50,000 Photography of the Study Site

Figure VI-5 1966 Photography of Road Intersection Site

Figure VI-6 1967 Photography of the Road Intersection Site

Figure VI-7 1968 Photography of the Road Intersection Site

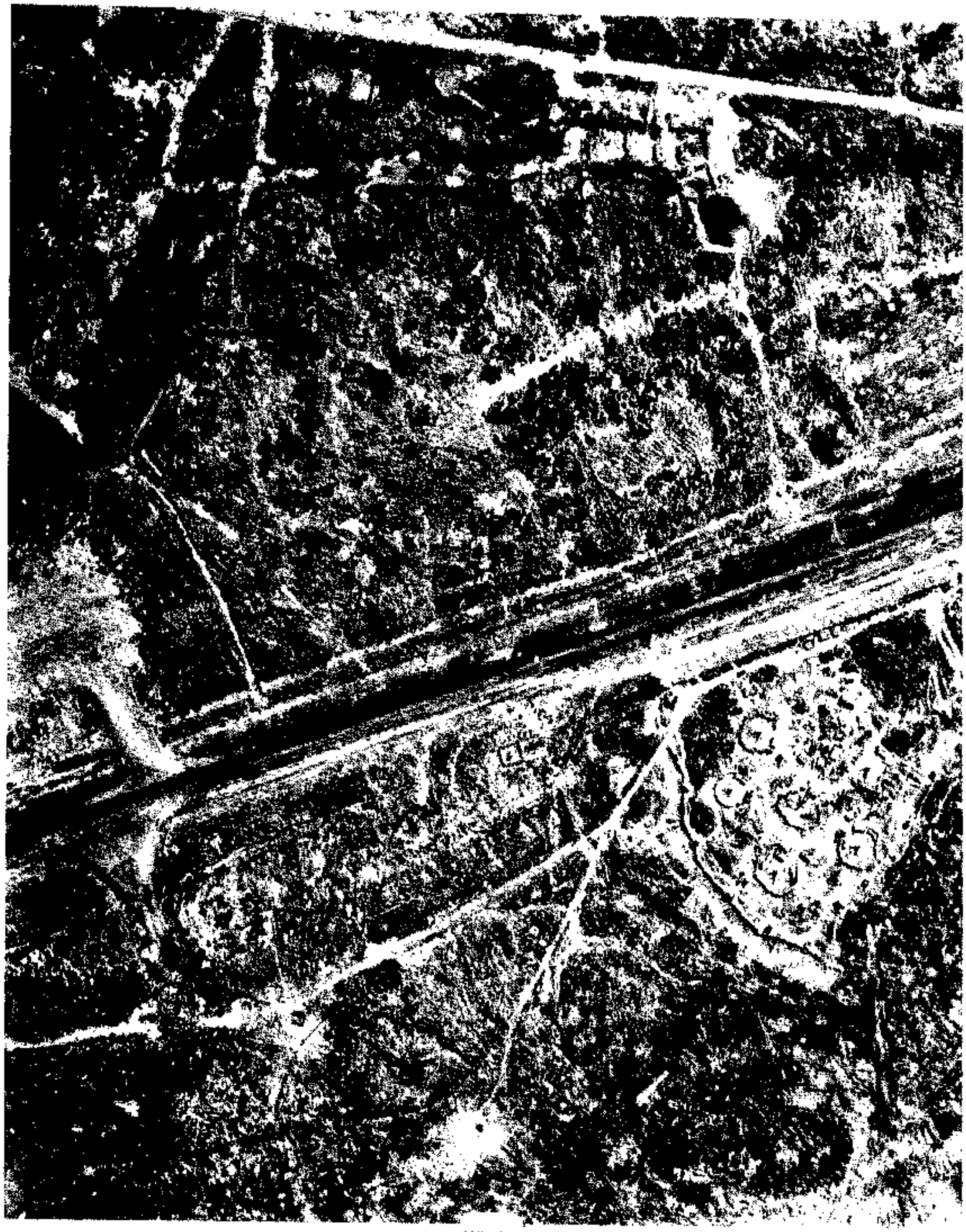
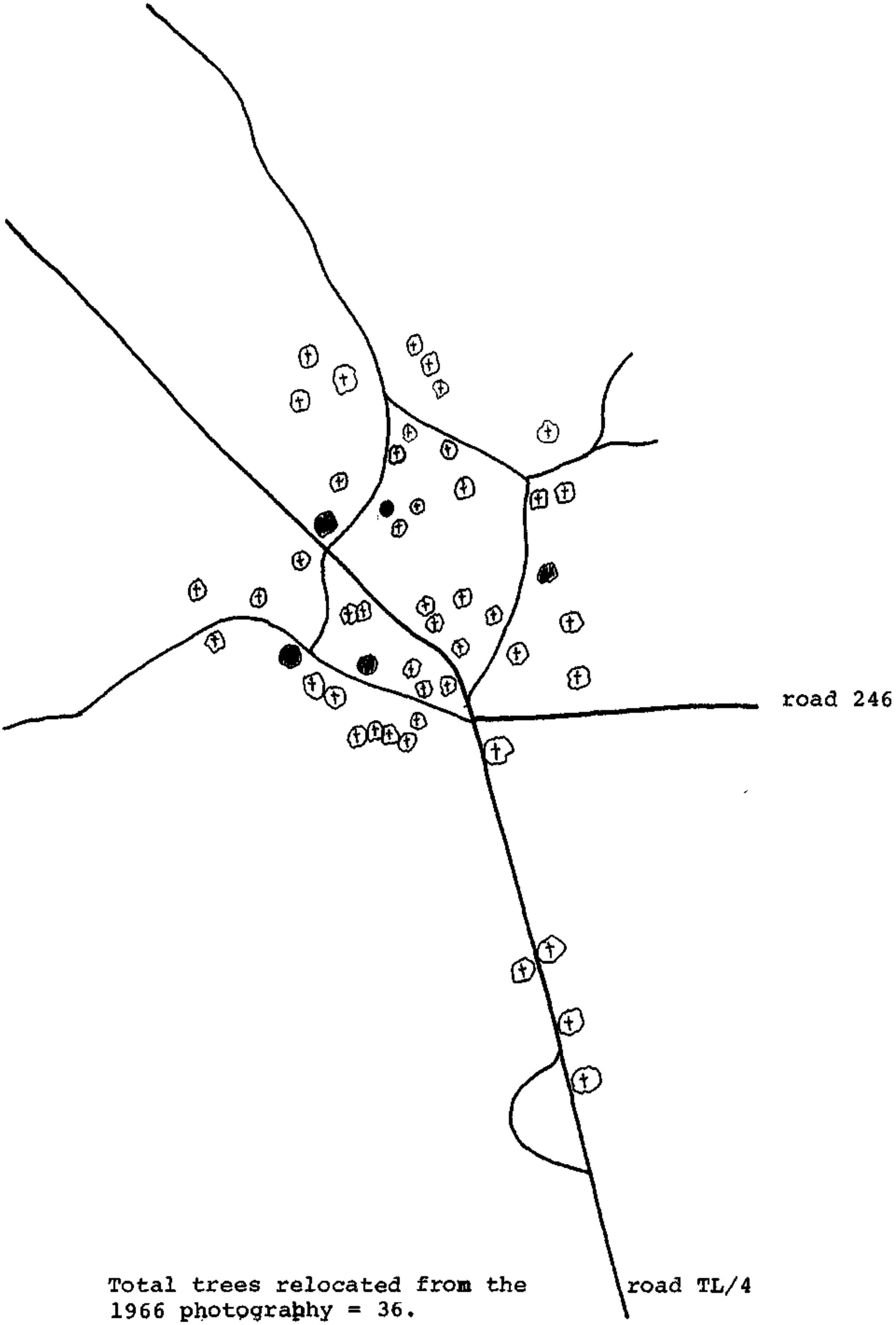


Figure VI-7a Close Up of Road Intersection Site from 1968 Photography

Figure VI-8 Major trees indicated on the 1966,XT, photography. Darkend area indicate live trees.



Total trees relocated from the 1966 photography = 36.

Figure VI-9 Major trees located on the 1967,XT, photography. Shaded area represent live tree, t, tepresent dead trees.

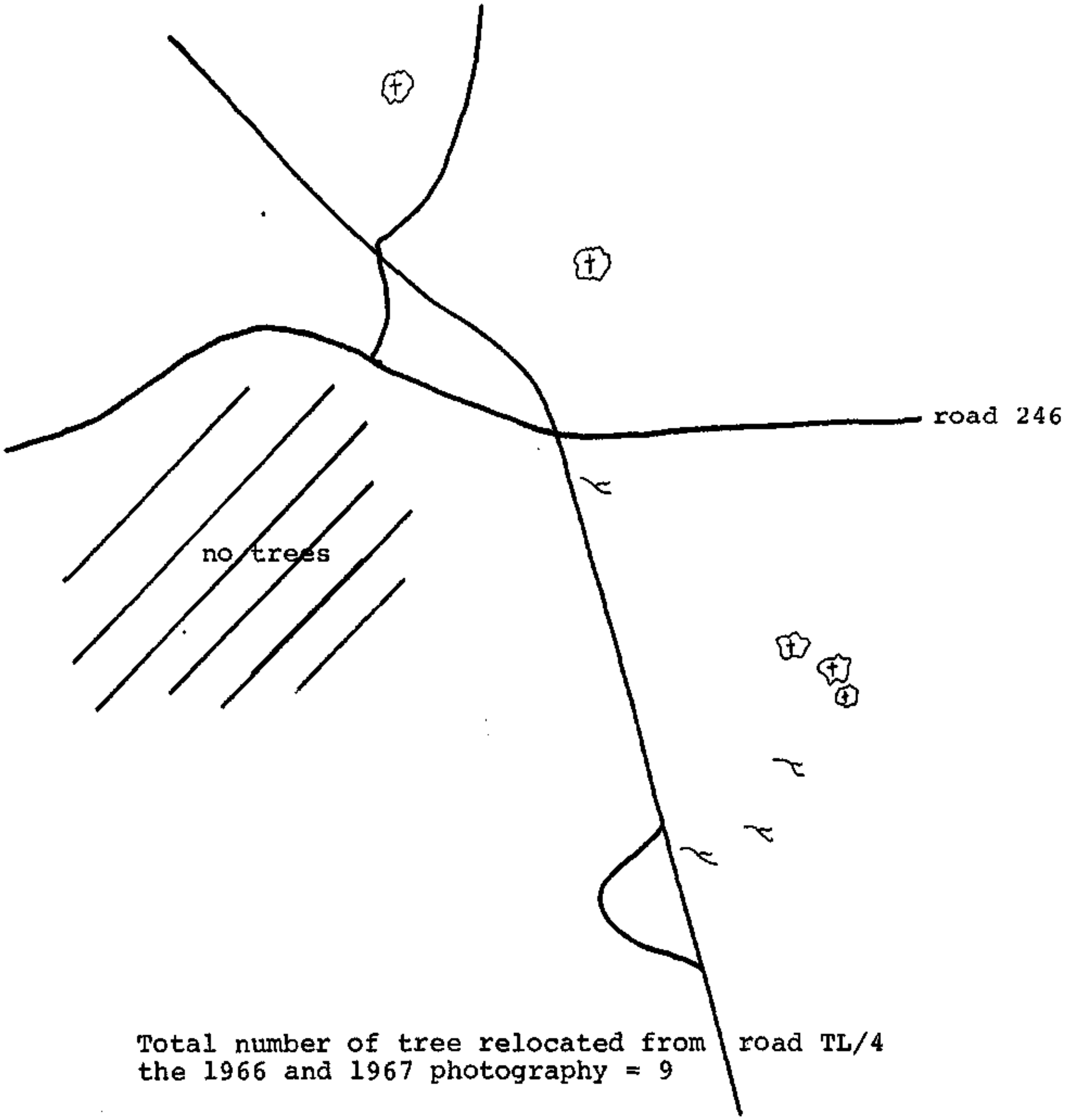


Figure VI-10 Major trees relocated from the 1966,1967 photos on the 1968 photography. ~ indicates down trees.

Figure VI-11 1966 Photography of Valley Site 1 Illustrating Forest Cutting and Burning Probably due to Shifting Cultivation Practices

e VI-12 November 1968 Photography of Valley Site 1. Area Covered by Figure VI-11 is Outlined by the Heavy Dashes.

Figure VI-13 1966 Photography of Valley Site 2

Figure VI-14 November 1968 Photography of Valley Site 2

Figure VI-15 1971 1:40,000 Photography of Study Sites. Note Apparent Recovery as Compared to 1969 in Figure VI-4.

VII. Comparison with Earlier Assessments

The study of the inland forests of South Vietnam made by the forestry team clearly indicated that military action stemming from the war induced major changes in the organization and structure of many of these forests. Some of these were related to forest modifications that had their origin in the herbicide treatments. Others were related to damage caused by bombing and shelling and by fire deliberately set or resulting from other military events. Commonly the modifications resulted from combinations of these activities.

To the extent that it was feasible, the forestry team attempted to separate the herbicide impact from other impacts and to provide an assessment of the effect of this activity. This assessment has been expressed in terms of cubic meters of merchantable and non-merchantable components of the forest.

Was the effect great or small? These are relative terms and the individual reader will undoubtedly make his own subjective judgement on the basis of his own frame of reference. For a forester whose frame of reference is notorious forest catastrophies of the past, the impact may by viewed as modest though surely not trivial. Table VII-1 gives a comparison of the estimated damage to merchantable timber due to herbicides in South Vietnam and some familiar catastrophic events that have occurred in the western hemisphere forests.

For the individual whose frame of reference is maintenance of the status quo in the forests of South Vietnam, the changes due to herbicides

Table VII-1 Comparison of Catastrophic Events in U. S. Forest with Vietnam Herbicide Damage.

Event	Location	Dates	Volume lost (ft.^{3})
Chestnut Blight	Eastern U. S.	1912-1940	9,000,000,000
Mountain Pine Beetle	Intermountain U.S.	1911-1935	5,000,000,000
Western Pine Beetle	Oregon	1912-1937	4,000,000,000
Tillamook Burn	Oregon	1933	4,000,000,000
Douglas fir Blowdown and Bark Beetle Epidemic	Washington & Oregon	1949-1952	3,000,000,000
Columbus Day Blowdown	Washington & Oregon	1962	2,500,000,000
New England Hurricane	New England	1938	750,000,000
SVN Merch. Vol.	SVN	1967-1971	43,960,950
SVN Inventory Vol.	SVN	1967-1971	58,630,000
SVN Total Vo.	SVN	1976-1971	112,080,000
Honduras Pine Beetle Epidemic	Honduras	1962-1964	1,419,500,000
Pine Beetle Epidemic in Southeast Texas	Southeast Texas	1958-1968	43,034,000
Tussock Moth Epidemic	Colville National Forest Washington	1932	50,100,000

use might appear to be very substantial.

From the vantage point of the person whose primary interest was to convert the natural forests to agriculture or to intensively managed forests, some of the changes induced by herbicides might indeed be viewed as advantageous since many of the trees that were killed were of weed specimens that would be girdled or poisoned under silvicultural practices used in other parts of Southeast Asia.

It was not the proper role of the Committee to make this sort of subjective judgement, but rather to attempt to record the change in the forest associated with military use of herbicides.

Unfortunately, large segments of the population of the United States, Southeast Asia and indeed the world, are likely to judge this assessment of herbicide impact within a frame of reference that was established by a series of reports that were highly subjective in character. Some of these reports were made by foresters and some by scientists whose professional expertise was quite outside of the field of forestry. Other reports were made by journalists and based upon their own non-professional observations and upon their interpretation of the reports couched their estimates of forest damage in terms of volumes of merchantable timber destroyed and monetary values associated with these volumes.

The estimates of volume of merchantable timber killed developed by this study are much less than these early estimates. Because this study will be judged by some within a frame of reference of these earlier reports was that made by Flamm (2). In his report to the AAAS Herbicide Assessment Commission Conference of June 14-20, 1970, he indicated that his assessment of damage was based on a combination of his own personal knowledge and on a report by Orians and Pfieffer (3) published in Science in May 1970. Flamm estimated the loss of standing merchantable volume to be 42,250,000 cubic meters which he valued at $490,100,000. He estimated the loss due to the growth retardation to be 1,250,000 cubic meters. For reasons given in the report, no effort was made by the forestry study team to attach a monetary value to this forest modification.

Westing (4) arrived at an estimate that was quite close to that of Flamm. He reported a loss of standing commercial volume of 40,000,000 cubic meters as contrasted with Flamm's estimate of 42,250,000 cubic meters.

Neither Flamm nor Westing present any data to substantiate these damage assessments. Both base their calculations of volume killed upon arbitrary assumptions concerning the pre-spray status of the impacted forests and the dosage response relationships appropriate to the applications of herbicides to these forests. They also based their assessments on incomplete information covering the areas impacted. Flamm (2) indicated in his assessment report that "these volume and dollar estimates of damage are only estimates, or indicators. They are subject to considerable dispute." Westing (4) in reporting quantitatively upon his assessment states that "the following interim estimates are based on a series of assumptions and on very little locally obtained data".

Unfortunately, a number of scientists and media writers who have been concerned about the total problem of war damage in South Vietnam have widely disseminated the Flamm and Westing assessments without recognizing and reporting the limitations which the authors themselves acknowledged.

This has been a problem for the forestry committee throughout most of its investigation, when it became apparent from preliminary findings that the study would produce an estimate of standing merchantable volume that was substantially less than earlier reports.

Accordingly, it is appropriate to examine the basic data and assumptions that led to the discrepancies. Both Flamm (2) and Westing (4) used an average volume of standing on merchantable timber in affected forest areas of 100 cubic meters per hectare as an underlying assumption in their damage assessment calculations. Since all other damage factors were introduced into the calculations as multiples of the basic standing volume assumption, the value assumed is of crucial importance.

A tropical forest that exhibited an average standing merchantable volume of 100 cubic meters per hectare would be a very rich forest indeed. It would have to be an essentially undisturbed natural forest with a substantial number of large trees of commercially valuable species. The distinguished French forester, R. Catinot (1) addressing the VII World Forestry Congress in 1972, stated with respect to tropical forest ecosystems that "as knowledge of these ecosystems advances, a certain disappointment is felt, so complicated is their study and so modest their wood production: 400 cubic meters per hectare of biological production and 5 to 50 cubic meters per hectare of economic production."

While there was no extensive forest inventory of South Vietnam, the inventories of comparable areas of the Indochina peninsula clearly indicated a low volume per hectare of merchantable timber in South Vietnam. Rollet's vegetation study indicated the same thing. These indicators of low commercial volume per hectare were confirmed by the inventory studies of this report, which produced an estimated average per hectare volume of standing exploitable merchantable timber of approximately 8 cubic meters per hectare. An adjustment of the Flamm and Westing assessment estimates to a suitable inventory base would bring their estimates to something of the order of 3.2×10^6 to 3.6×10^6 compared to the estimate in this study of 1.25×10^6.

The remaining discrepancies result from differences in assumptions concerning the dosage response and the areas impacted with various frequencies.

An indication of the confusion which can arise out of misconceptions concerning basic inventory and its relationship to damage is contained in a number of documents prepared by the government of South Vietnam.

A memorandum from the Director of Water and Forest addressed to the Secretary General of the Ministry of Land Reform and Agriculture and Fishery Development dated March 3, 1971, reported a study of the effect of defoliation on forests. This study was made by asking the provincial forestry services and/or districts to estimate damage in their areas. Their estimates were based upon a study of 839,013 affected forest hectares.

The estimates of damage were for commercial wood 1,464,88 cubic meters. Of this amount, 1,278,382 cubic meters was Class III and better. This compares to the forestry study team estimate of 1,250,000 cubic meters. The South Vietnamese study then estimated that 4,549,855 cubic meters of fuelwood was damaged by herbicides. This would be comparable to a portion of the 5.05 to 11.15 million cubic meters of damaged non-merchantable wood estimated by the forestry study team. The report however, then goes on to state:

If computed on the basis of 90 cubic meters per hectare according to the forest statistics in Cambodia, the quantity of wood is as follows:

90 cubic meters x 839,013ha = 75, 511, 170 cubic meters

If we compare the above amount with that estimated by the provincial forestry services or districts we realize that the estimates made by these services or districts are too low (8%). The reason why this big difference exists is that the provincial forestry services or districts made their estimates based on the amount of wood usually exploited per year without considering other unexploited species of wood. While the inventory has not been made, we temporarily accept the modest amount estimated by the provincial forestry services and districts.

Clearly the Directorate of Water and Forest is confused concerning the relationship between the reports from its field officers and what it views as the Cambodian inventory values. In point of fact the Cambodian inventory shows a much lower volume than this when all forest types are considered. The 90 cubic meter per hectare figure represents the inventory volume on dense forests for trees of commercial size and species uncorrected for actual utilization standards. This forest type represents only 11 percent of the area. The major area covered in the Cambodian inventory is in thin forests and in secondary forests. These types represent 49 percent of the forest land and carry very low merchantable volumes even on a mensurational inventory basis without adjustment for current utilization standards.

As previously noted the disparity in assumptions concerning the pre-spray inventory of the affected forests accounts for approximately 90 percent of the differences between the Flamm and Westing assessment and that of the forestry study team.

A second source of discrepancy lies in the assumptions concerning area impacted. Table VII-2 indicate the areas of the inland forest impacted once and more than once as determined by the forestry study team from Department of Defense mission records and the corresponding assumptions made by Flamm and Westing:

Table VII-2 Comparison of Area Sprayed Determined from Department of Defense Mission Records and Assumed Areas Sprayed of Flamm and Westing.

Impact Frequency	CEHV Forestry Study Team	Flamm	Westing
once	694,105 ha	900,000 ha	1,500,000 ha
more than once	385,494 ha	450,000 ha	500,000 ha

A third source of differences arises from the assumptions concerning response at various levels of treatment. The Flamm and Westing analyses dealt with two levels of impact namely; sprayed once and sprayed more than once. The forestry study team analysis indicated that this two level breakdown was inadequate to express the effect of herbicides and instead developed a more sensitive regression relationship based upon four levels of impact. It may be useful, however, to examine the differences between these early assessments and the present one on the basis of the two level response analysis of Flamm and Westing.

Both Flamm and Westing examine damage by estimating a mortality loss percentage for the area sprayed once and area sprayed more than once. It would be useful to obtain a comparison of their mortality response for the whole inland forests as compared to that of the study team. The study team determined that the weighed average number of sprayings per hectare over the 1,080,037 hectares sprayed is about 1.8 sprayings per hectare. Examination of the mortality response curve discussed elsewhere in this report. indicates that this rate corresponds to about an 11% mortality. For comparison, we can weight the mortality percents used by Flamm and Westing by the correct area sprayed once and more than once to obtain the average pe~cent kill of their analyses. This done in Table VII-3 and indicates that Flamm used an overall percent kill of about 36% or roughly 3 times that of the study team and Westing used an overall percent kill of about 28% or roughly 2.5 times that of the study team.

It is important to understand that the major source of discrepancy between the widely publicised Flamm and Westing analyses and the CEHV forestry study team analysis was very largely a function of differences in the basic assumptions concerning the nature of the forest prior to herbicide spraying and the areas of forest treated at various levels.

Differences in assumptions concerning response at various levels were real but represented a relatively small component of the major discrepancy between the CEHV analysis and the earlier assessments to a suitable inventory.

Table VII-3 Determination of Overall Average % Mortality Used by Flamm and Westing.

	Number of Sprayings/ha	Correct area	% of Kill	Weighted Average Kill
Flamm	1	694386	10-20(15)	36%
	≥2	385651	75	
		1080037		36%
Westing	1	694386	10	28%
	≥2	385651	60	
		1080037		28%

One may question that these averages are misleading in terms of the actual (although incorrect) areas used by the authors, however, the weighted average mortality they actually used was approximately 22% by Westing and 35% by Flamm.

References

1. Catinot, R. 1972. Biological and economic opportunities and limitations to the manipulation of the tropical forest ecosystem. VII World Forestry Congress. October

2. Flamm, B. R. 1970. Forestry in Vietnam and the effects of defoliation on the forest resources. Draft copy prepared for presentation at AAAS Herbicide Assessment Commission Conference, Woods Hole, Mass., June 14-20, 1970

3. Orians, G. H. and E. W. Pfeiffer. 1970. Ecological effects of the war in Vietnam. Science, 168:544-554

4. Westing, A. H. 1971. Forestry and the war in South Vietnam. Journal of Forestry, 69:777-783