SPEY

The Effects of Herbicides in South Vietnam

PART A – SUMMARY AND CONCLUSIONS

Committee on the Effects of Herbicides in Vietnam
Division of Biological Sciences
Assembly of Life Sciences
National Research Council

National Academy of Sciences
Washington, D.C.
1974

NOTICE

The project which is the subject of this report was approved by the Governing Board of the National Research Council, acting in behalf of the National Academy of Sciences. Such approval reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the committee selected to undertake this project and prepare this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. Responsibility for the detailed aspects of this report rests with that committee.

Each report issuing from a study committee of the National Research Council is reviewed by an independent group of qualified individuals according to procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved, by the President of the Academy, upon satisfactory completion of the review process.

This study was supported by Contract No. DAHC15 71 C 0211 between the Department of Defense and the National Academy of Sciences, and by funds furnished by the National Academy of Sciences.

Library of Congress Catalog Card Number 74-247.

The Committee on the Effects of Herbicides in
Vietnam. Division of Biological Sciences.
Assembly of Life Sciences. National Research
Council.
The Effects of Herbicides in South Vietnam:
Part A. Summary & Conclusions.
Wash., D. C. National Academy of Sciences

1974 1-21-74

ABBREVIATIONS USED IN THIS REPORT

ARVN	Army of the Republic of Vietnam
CINCPAC	Commander in Chief, Pacific
CORDS	Civil Operations and Rural Development Support
DOD	Department of Defense
DRVN	Democratic Republic of Vietnam
HERBS	Acronym for computerized records of herbicide spray programs
HES	Hamlet Evaluation System of CORDS
JUSPAO	Joint United States Public Affairs Office
MACV	Military Assistance Command, Vietnam
MR	Military Region
NAS	National Academy of Sciences
NLF	National Liberation Front
NVA	North Vietnamese Army
RVN	Republic of Vietnam
RVNAF	Republic of Vietnam Armed Forces
SVN	South Vietnam
USAID	United States Agency for International Development

NATIONAL ACADEMY OF SCIENCES

OFFICE OF THE PRESIDENT
2101 CONSTITUTION AVENUE
WASHINGTON, D. C. 20418

February 15, 1974

The President of the Senate
The Speaker of the House of Representatives
The Secretary of Defense

Sirs:

I have the honor to transmit the report of the National Academy of Sciences on the effects of the program of herbicide spraying in South Vietnam. This report was prepared pursuant to Public Law 91-441 of 1970.

As the ability of organized societies to destroy each other by military means has escalated, it has become increasingly necessary to attempt to limit warfare to the actual combatants and the accomplishment of immediate military objectives. To these ends, international agreements have been directed, for example, to humane treatment of prisoners of war, respect for hospitals, recognition of military medical personnel as noncombatants, and avoidance to the extent possible of all but truly military targets. Thus, also, has our government agreed to eschew the use of biological and chemical weapons.

To be sure, given the intrinsic irrationality of war, if flame-throwers, high explosive weapons, laser-guided bombs, and all the rest are deemed to be "acceptable," one may reasonably ask how one can rationalize outlawing any other weapon or procedure on the ground that it is still more inhumane? Nevertheless, just as men of good will, in all nations, agree that a principal burden upon governments is to utilize diplomacy and negotiation -- rather than arms -- to settle differences, so, too, are they agreed that governments must continue to press for international agreements which, to the extent possible, will limit military actions to the achievement of immediate military ends, minimizing all other associated brutality, horror and destruction of the natural and man-made worlds. Indeed, it is the difficulty in thus containing the effective dimensions of nuclear weapons which has rendered their use so abhorrent that they have become weapons of last resort. And it was such concerns, inter alia, that led to the present study.

The more commonly used herbicides are synthetic chemical analogues of the hormones that, in the normal developing plant, regulate its rate and pattern of growth. Because of their specificity -- causing aberrant growth or death of some plant species while without effect on others -- these herbicides have found wide use in agriculture and home gardening. Indeed, the American capability to feed ourselves and also provide 70 percent of all of the food surplus, anywhere on the planet, which now can be made available to feed those in less fortunate nations, derives in significant measure from the use of this same class of chemicals.

In the course of the war in Southeast Asia, these herbicides were utilized on a large scale for military purpose, predominantly for defoliation of dense forest so as to permit detection of enemy military and supply units, and to lesser degree for crop destruction and a variety of other purposes. The general procedure was to dispense solutions of herbicides from fixed-wing aircraft or helicopters so that a fine spray would envelop the vegetation below. As the magnitude of this program increased, thoughtful individuals considered it desirable to inquire into the acute and persistent effects, if any, of such herbicide usage on the Vietnamese population as well as on the fauna and flora of the region. Presumably, the findings of such an examination could (a) contribute to the assessment of damage to Vietnam which will be required to plan future efforts to reconstruct that country and repair the ravages of war, and (b) assist in judgment as to whether, in the future, such herbicide usage should be considered to fall within or outside the category of chemical warfare to be eschewed, as defined in the Geneva protocols.

As an expression of this concern, the Congress, in Public Law 91-441, directed that:

> (1) The Secretary of Defense shall undertake to enter into appropriate arrangements with the National Academy of Sciences to conduct a comprehensive study and investigation to determine (A) the ecological and physiological dangers inherent in the use of herbicides, and (B) the ecological and physiological effects of the defoliation program carried out by the Department of Defense in South Vietnam.
>
> (2) Of the funds authorized by this Act for research, development, testing, and evaluation of chemical warfare agents and for defense against biological warfare agents, such amounts as are required shall be available to carry out the study and investigation authorized by paragraph (1) of this subsection.

On 26 October 1970, by a letter addressed to the Director of Defense Research and Engineering, the Academy accepted this responsibility. The Academy has a long tradition of scientific assistance to the national defense and it desires also to be of whatever assistance it can in furthering our ability to minimize the undesirable secondary consequences of warfare without sacrificing the capability of the American military establishment to assure the national defense. Hence, with the understanding that the resultant report to the Department of Defense and to the Congress would be made public, we were pleased to accept this task. Contract DAHC15 71 C 0211 between the Academy and the Department of Defense, to provide funds and other support for this endeavor, was signed on 8 December 1970.

Arrangements for the study: As we entered upon the task, some of its inherent difficulties were self-evident: Appraisal of the effects of herbicide usage, necessarily, had to be undertaken well after the fact. Since the war in South Vietnam was certainly not conducted as a controlled experiment, valid conclusions might well be seriously constrained by the complexity of actual circumstances, by lack of adequate records or qualified observers on the scene at the time of the spraying program. Patently, separation of the effects of herbicides from all other aspects of the war would be difficult at best. Most importantly, military activity was and still is continuing in most of the areas which had previously been sprayed with herbicides; accordingly, safe access to large areas of the country was denied to our field teams, thereby in no small measure frustrating their efforts to secure critical data. Indeed, several of our Committee now know the sensation of being in an airplane subjected to fire from the ground.

The present report was prepared by an especially appointed ad hoc Committee on the Effects of Herbicides in Vietnam, working, administratively, within the Division of Biology and Agriculture of the National Research Council. Each member of the Committee was especially selected for his specific technical competencies. Professor Anton Lang of Michigan State University, a member of the Academy, renowned plant physiologist and authority on plant hormones accepted the invitation to chair the Committee. A deliberate decision was taken to enroll, as full-fledged members of the Committee, a number of scientists from countries other than our own. A distinguished Vietnamese scientist, Professor Le-Van-Thoi, President of the National Scientific Research Council of Vietnam, agreed to serve as Associate Chairman; other members are from South Vietnam, Canada, England and Sweden.

The early planning for this study indicated the desirability of including, on the Committee, one or more appropriately qualified anthropologists. However, formation of the Committee was significantly delayed when anthropologists indicated their reluctance to be associated with this effort because the supporting funds were to be provided through the Department of Defense, an attitude formalized by the American Anthropological Association. A meeting to resolve this question, arranged by the Division of Behavioral Sciences of the National Research Council, was attended by several senior anthropologists, albeit not as formal representatives of the American Anthropological Association. Subsequently, one senior anthropologist undertook to serve without any qualifying reservations, while another agreed to participate provided that the funds to be utilized in support of his specific activities, within this project, would derive from some source other than the Department of

Defense. Concerned that the study be neither unduly delayed nor seriously incomplete, the use of private funds from the endowment income of the Academy was authorized for this purpose.

When the study began, it was recognized that much of the basic information concerning herbicide usage in South Vietnam was classified by the Department of Defense and not available to the public. In an exchange of correspondence on this subject, the Defense Director of Research and Engineering indicated that:

> ...I would like to assure that all information which may be required in its conduct will be supplied by the Department of Defense regardless of classification.

Subsequently, he wrote that:

> This acknowledges your letter of 26 October recommending declassification of DoD data on herbicides for use by the National Academy of Sciences study.
>
> ...I agree that your committee must have access to these data and that they should be declassified. However, premature release of these data, and their subsequent partial evaluation and publication by either scientists or journalists prior to publication of your study, would not be in the best interests of either of us. I suggest that the data should be restricted to the use of your committee until your report is published. At that time the data could be placed in the public domain....

Later, in a letter concerned with various detailed arrangements for the study, I stated that:

> ...It is further understood that the Department is prepared to make available on a privileged but otherwise non-classified basis all information and data in its possession directly related to the matters under consideration as well as

full access to various civilian and military personnel whose particular experience and information may be considered necessary in the development of the study program....

On this basis, without requirement for security clearance of those Committee members who had not previously undergone clearance for other reasons, the work was undertaken.

The present report is only a summary of the full activities and findings of the Committee; a more complete account will be made available as soon as possible. This summary report has been subjected to an unusually intensive review by an ad hoc panel of Academy members appointed by our Report Review Committee. In a constructive dialogue, the authors of the report responded to numerous questions, suggestions and criticisms of the review panel.

Findings and Conclusions of the Report -- A Commentary.

The report provides its own summary and recommendations. It may, however, be of assistance to the reader to comment upon some of the principal findings of the report and their significance.

1) The Committee was unable to gather any definitive indication of direct damage by herbicides to human health. However, to a greater extent than in other areas, there were consistent, albeit largely "secondhand," reports from Montagnards, of acute and occasionally fatal respiratory distress, particularly in children. The inability of the Committee to visit the Montagnards in their own locales so as to verify these tales, is greatly regretted. Although these reports did not come from medically qualified observers, the Committee considers it to be important that this matter be pursued at the earliest opportunity.

Considerable attention was paid to the possibility, suggested previously, of birth defects induced by herbicides or by contaminants in herbicide preparations; no evidence substantiating the occurrence of herbicide-induced defects was obtained. However, the potentially most definitive aspect of this examination has not yet been completed.

2) Attempts to assess the social, economic and psychological effects of the program of herbicides spraying on the peoples of South Vietnam were less than satisfying. Certainly the impact of the spraying program on that population now appears relatively trivial as compared with other aspects of the upheaval in that country. Evidence was obtained that numbers of families moved away from their traditional homes because of the herbicide spray program, but few were actually identified. The fertility of their land, however, was not reduced thereby and it should not be residual effects of the crop destruction program, *per se*, which prevents their return. On the other hand, small land holders growing tree crops, e.g., coconuts, definitely suffered more lasting economic damage.

Other than the belief reported to be prevalent among the Montagnards that spraying was directly responsible for acute illness, by and large the South Vietnamese appear to hold no consistent views with respect to alleged health hazards resulting from exposure to herbicide spraying, although many are greatly concerned with this possibility. Only in part did such fears as were expressed appear to find their origin in propagandistic activities.

Although available toxicological information had indicated that, within a considerable dosage range, the herbicidal compounds are relatively innocuous, no sizeable human population had previously been thus exposed. Moreover, at the time the program began, it was not known that preparations of the herbicide, 2,4,5-T, were contaminated with the extraordinarily toxic compound, TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin), about 200 to 300 pounds of which, mixed with about 50 million pounds of 2,4,5-T, were dispensed over South Vietnam. That no serious sequelae have since been definitely discerned is fortunate indeed. However, the continued presence of possibly significant concentrations of this material in fish in inland rivers, taken as recently as 1973, is considered to be a matter that warrants further attention.

On balance, the untoward effects of the herbicide program on the health of the South Vietnamese people appear to have been smaller than one might have feared.

3) The effects of herbicides on vegetation were largely confined to those resulting from direct contact during spraying. It was found that the various herbicides

disappear from the soil at a rate sufficiently rapid as to preclude any significant effect on the next crop of food plants, or on the next growing season of trees, shrubs, etc.

All evidence indicates that standing food crops, of all sorts, were highly vulnerable to the spray program. It was not possible, however, to assess the nutritional consequences of that program on the affected local populations.

4) A major effort of the Committee was devoted to appraisal of the effects of the herbicide spraying program on the forests of South Vietnam.

a) The mangrove forests were found to have been extremely vulnerable. One spraying resulted in the death of virtually all exposed trees, in this case, about 36 percent of the entire mangrove forest, equal to about 0.6 percent of the entire area of South Vietnam. It is estimated that these forests will not spontaneously recover for well nigh a century, if at all; reforestation by a program of massive planting of seedlings could reduce the time required to about two to three decades.

Concomitant with this devastation has been a significant reduction in the more valuable fauna of the waters of the region; however, several other changes appear to have been contributory at the same time, and it is difficult to know how significant the death of the mangroves was to this process. The dead mangroves are being harvested for fuel now, as in the past, although this occupation supports fewer individuals today than before the war. The economic loss, therefore, will be sustained in the future, when the forest has been stripped, unless a vigorous replanting program is undertaken. If this is not done, mankind will have been guilty of a large and ugly depredation of our natural heritage.

b) The bulk of the herbicide spraying program was addressed to the large inland forests of South Vietnam; of the total of about 25.9 million acres of such forests, at least 10.3 percent (6.5 percent of the total land area of South Vietnam) was subjected to one or more sprays. Unfortunately, for lack of military security, this area could not be examined on the ground by the Committee.

The appraisal of herbicide effects in the inland forests, therefore, necessarily rested virtually entirely upon interpretation of aerial photography, some of which was already available but most of which was obtained at the request of the Committee. Unfortunately, photointerpretation of damage to an essentially unfamiliar forest is extremely difficult; quantitative estimates may be accepted as reasonably reliable only if an acceptable sample can also be checked on the ground. Although no such opportunity was available, the Committee had no other alternative.

No other aspect of these studies engendered difficulty and controversy as did the estimate of damage to the inland forests. The original approach to this question was to appraise the damage in terms conventional to professional forestry, viz., the volume of "merchantable timber" represented by standing dead "merchantable trees," i.e., trees of such size and quality as to have been candidates for timbering by the commercial practices of the region. Assessment was undertaken in these terms because a) it limits the assessment to the larger trees, more readily identified by aerial photography, b) such an assessment might make possible an estimate of economic loss, and c) preliminary estimates, in these terms, had already been published. Trees which have disappeared are not counted by this procedure and standing trunks of large trees which have lost much of their crowns may be difficult to identify. However, dead trees of the commercially more valuable species commonly stand for several years before falling.

When the initial estimate, in these terms, proved to be strikingly smaller than previously reported preliminary estimates by others, it encountered scientific incredulity among members of both the working Committee and the Report Review panel and engendered, in varying degree, an antagonism which was conditioned by the turbulent emotions which are the legacy of the American experience in the Vietnam war. While the latter situation lasted, it hindered progress of the study by focusing attention on this single parameter. For months, it diverted attention from full appreciation of the fact that such a summarizing, overall figure can be truly meaningful only if a single spraying were uniformly damaging, as it is to the mangroves, and from appreciation that such a figure cannot reveal differential effects of one spraying as compared with multiple sprayings, differential effects on different types of forest, or on the merchantable trees as compared either with the growing stock or with trees of non-merchantable quality -- were there any such differential effects.

The resultant challenges to the estimate ultimately proved useful. Intensive rescrutiny of the data by the Committee resulted in significant upward revision of the quantitative estimate of damage and directed attention to the differential effects that the report now emphasizes. The report reveals that the Committee now considers that multiple sprayings will be devastating to any forest, as it was to these, and that even a single spraying can be very serious in relatively open forest and lethal to forests of particularly susceptible species. It remains possible that the Committee's estimate of the gross kill of merchantable timber will prove to be significantly lower than reality; if so, that will certainly be meaningful, but it no longer seems to be the central question. The extent and nature of total damage to the forest cannot adequately be expressed by this single statistic.

Meanwhile, months of intensive discussions, joint inspections of photographic material, refinement of procedures and of calculations, challenges and rebuttals were required in order to erase suspicion and relieve discord. To the extent that there remains concern for the accuracy of the Committee's estimate of the loss of merchantable timber in the inland forest (see below), that concern should now rest solely on scientific grounds. This painful episode is recounted in further evidence of the multitudinous, sometimes subtle effects of the Vietnam war on the American people.

The Committee's final estimate of the total volume of merchantable timber in standing merchantable trees killed by herbicides in the inland forest is about 1,250,000 m^3, i.e., within a range of from 500,000 to 2,000,000 m^3, out of a total stock of "merchantable timber" in the sprayed area estimated to be about 8,500,000 m^3. The records are known to underestimate the total sprayed area; both estimates are, hence, understated proportionally.

When the fact of the disparity between the Committee's original estimate and previous estimates was recognized, a team of three independent photointerpreters and forestry experts was invited to review the procedures which had been used and to make an independent appraisal of the total damage to the inland forests, utilizing the photographic materials available to the Committee. Their estimate, based on a necessarily limited examination of the available material, was of the order of the top of the range now reported by the Committee. However, one member of this group, after a second examination of the photographic material suggested that the loss of merchantable timber may be a few times greater than that here reported by the Committee. In addition, a member of the Report Review panel has informed his colleagues that, also utilizing some of the materials gathered by the Committee, he estimates the amount of merchantable timber in the trees killed by herbicides in the inland forest to be significantly greater even than that estimated by the independent consultant. He has been invited to publish his analysis in the open literature.

The differences among these estimates arose from differences in the actual counts of dead trees in a given sample area, the specific samples used and the validity thereof, the total volume of merchantable timber assumed to have been in the forest before the spraying, etc. It may be noted that the sample areas examined by the Committee were decidedly larger than those utilized in formulating the other estimates and that the Committee gave considerable attention to weighing the relative contributions of those areas which had been sprayed zero, once, twice, thrice, or four or more times. However, it is not clear to what extent these differences contributed to the differences among the results. Patently, definitive resolution of these substantial differences will not be possible until an appropriate survey of the area can be made on the ground.

It is not clear, in any case, what social, economic or ecological significance to impute to the estimated parameter, i.e., the volume of "merchantable timber" killed by the spraying. As long as the dead trees stand, they do not necessarily represent "economic loss" since, were peace restored, there would still be opportunity to timber many of these trees, provided that the necessary labor and mill capacity were available. Similarly, trees killed by herbicide spraying that have disappeared because they were taken down for timber or fuel do not represent economic loss.

Accordingly, the Committee sought other indicators of the extent of damage to the forest. Several other observations by the Committee seem more descriptive of the consequences to the forest of the spraying program than is the absolute value assigned to the volume of merchantable timber killed by herbicides:

i) Two-thirds of the area sprayed in the inland forest was sprayed only once. The dead merchantable trees in such areas, in excess of those expected from normal mortality, were found to be rather variable and generally few in number. The impression was gained that most of these areas, particularly in the dense forest, will spontaneously recover in due course, with the distribution of species probably much as it was before.

ii) The number of dead merchantable trees per unit area increased with multiple sprayings. Areas sprayed three or more times were extremely hard hit; in some areas more than half of all "merchantable trees" were killed. These areas, perhaps 12 percent of the total sprayed area, are unlikely to recover without a major effort at assistance.

iii) The bulk of the biomass in much of the forest consists of non-merchantable trees, viz., trees below merchantable size (growing stock) or of non-merchantable quality. When killed, these trees generally decompose and disappear much more rapidly than do "merchantable trees." Although quantitative estimation of damage to this component of the forest biomass is not feasible by aerial photography, the Committee notes that the loss of such material due to herbicide spraying was extensive in relatively open forest and less serious in the dense, heavily canopied forest; as a very rough approximation the Committee suggests that the loss of such material may have been of the order of 5 to 13 million m^3. The report further notes that:

> One clear conclusion reached by the Committee is that the greatest damage which the inland forests suffered from war activities, including herbicides, has been incurred by the heavily overused open or

thin forests and by the young secondary forests emerging from abandoned swidden. This damage does not appear in the assessment of merchantable timber loss since it represented loss of growing stock below merchantable size and of the early stages of forest regeneration. In these forests the loss of seed sources may be a very critical factor even though the merchantable volume of lost seed trees was quite small. High mortality of seedlings, saplings and young trees, not reflected in merchantable timber loss, in many cases resulted in setting the succession back for many years. But this loss, though very real, could not be quantitatively evaluated without far more extensive studies on the ground than those we were able to conduct.

...Damage due to bombing and shelling, whether or not it was associated with herbicide treatment, may well be the most serious and long lasting of all of the war impacts on the inland forest. In the large areas cleared by bombings, not only the merchantable timber, when present, was destroyed but so was all of the growing stock in the opening. Extending far beyond the dimensions of the opening in the forest created by the bomb strike is the damage to living trees caused by shrapnel. These metal fragments in the living trees have already created serious problems for the manufacturers of forest products in SVN in terms of equipment maintenance, loss of yield, reduction in mill productivity and serious hazards to the operating personnel, and these problems will persist long after the residual effects of herbicide damage have disappeared. These problems may indeed reduce the opportunities to sell South Vietnamese logs in the international market and to establish new wood-using industries in SVN....

...Future development of a viable forestry program in SVN, including forest management and development of utilization facilities, will have to be based upon study of the unusual conditions induced by war damages, separately and in combination. Areas where growing stock has been depleted and where regeneration has been inhibited will need to be given special treatment to restore productivity. The longer the delay in taking these measures the more difficult and costly will be the rehabilitation.

Thus, whereas one cannot rationally assign some dollar value to the herbicide-caused economic loss to Vietnam, either in the past or the near future, there will be serious penalties in the long term unless a commensurate effort is undertaken to prevent them. And, as in the case of the mangroves, there is the burden of conscience to restore these forests to their natural or improved condition.

The Academy is grateful to the Committee, its staff, its consultants, and our reviewers, all of whom gave unstintingly of themselves in the major effort herewith reported.

This highly informative report cannot, by itself, provide definitive answers to all of the questions held by the Congress at the time of passage of Public Law 91-441. However, considering the adverse circumstances under which it was prepared, we consider the report to be a most significant accomplishment. We trust that it will prove to be a meaningful contribution to understanding and a useful guide for future decisions.

Respectfully yours,

Philip Handler
President

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES NATIONAL ACADEMY OF ENGINEERING

2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418

DIVISION OF BIOLOGY AND AGRICULTURE
COMMITTEE ON THE EFFECTS
OF HERBICIDES IN VIETNAM

TELEPHONE: (202) 961-1761

February 11, 1974

Dr. Philip Handler, President
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Handler:

I am herewith transmitting to you the summary report of the Committee on the Effects of Herbicides in Vietnam.

When, almost exactly three years ago, I agreed to direct this study as Committee chairman, I questioned whether the study of one particular impact of the war in South Vietnam would be very productive. It was clear even then that the country had suffered from many war related disturbances and that the effects of such would be closely intertwined; to disentangle one effect would neither be easy, nor provide a comprehensive assessment of the consequences of its use.

My concern over the feasibility of this assignment was deepened with my first visit to South Vietnam. It became very clear at that time that the accounts which we had been given of the improved security and safety situation, while perhaps quite true for cities and larger settlements, did not apply to outlying areas--especially the mangrove and inland forest--which had been exposed to the heaviest herbicide sprayings and which therefore we needed to visit and study in detail. I accepted your appointment despite these handicaps because of my belief in the importance of determining the nature and scale of these effects and because the longer the assessment might be delayed, the lesser became the prospects of obtaining meaningful data. I believe these feelings were shared by all those who accepted appointment to the Committee.

The limitations within which the Committee had to work necessitated some profound and often agonizing revisions in our plans; agonizing in that we often had to accept less than ideal alternatives, whether in regard to the extent of a study or the techniques utilized. There was one principle that was maintained on which I and the members of the Committee from the outset had placed the greatest importance: our studies must be approached in a quantitative manner. However, the extent to which a problem could be so studied under these conditions varied greatly. An inventory of the herbicide operations--what fraction of the various vegetation types had been sprayed, and how many times--was done for the whole country. Damage to inland forests was assessed on a substantial and representative sample. Impact on settlements was studied in 18 areas reaching from the southernmost tip of the country to the latitude of the City of Hue in the north. Other studies could be done only in one or a few selected sites, and generalizations, if any, made only with strong qualifications. In some important problem areas, our results did not permit any conclusions. This quantitative approach, although it limited the extent of problems which could be studied, was preferable to collecting a larger quantity of qualitative, anecdotal data inasmuch as these latter would not have permitted any generalizations.

To the extent possible in a study of this nature, all results and conclusions are documented by data. However, the supporting material gathered by the Committee is voluminous and is both quantitative and qualitative. Much of it is in the form of working documents prepared by individual Committee members and/or consultants and will be submitted for publication in the near future. It should provide further opportunities for study and analysis by others who may follow.

To my regret, it has not been possible to obtain a consensus of all Committee members on all sections of this report. Professors Pham Hoang Ho, Alexander Leighton, and Paul Richards have disassociated themselves from the section dealing with the quantitative assessment of damage to the inland forests (IV B 3). Their statements of exception are reproduced in a section immediately following the text of the report. I respect their exceptions although I believe the assessment of forest damage was conducted by individuals with great experience and an impeccable record in forest surveys of this nature. I must add that this study was very complex indeed and spans a very wide spectrum of disciplines. Therefore, the individual members of the Committee should not be held accountable for every part of the entire report.

In presenting this report I wish to recognize and commend to you the enormous contribution of the members of the Committee. They remained dedicated even when it became necessary to scrap or alter study plans, and although all were engaged with other pressing commitments they never refused to place at our disposal their time, their thought, or their personal convenience. The consultants and associates of the Committee also deserve highest praise, as does the Committee staff and especially the Committee's principal staff officer.

Respectfully,

Anton Lang

Anton Lang
Chairman

Committee on the Effects of Herbicides in Vietnam

Anton Lang, Chairman
Director, MSU/AEC Plant Research Laboratory
Michigan State University
East Lansing, Michigan 48824

Lê-Văn-Thới, Associate Chairman in Charge of Liaison with Vietnamese Scientists
President, National Scientific Research Council of Vietnam
Atomic Energy Office
291, rue Phan-thanh-Gian
B.P. Q-16
Saigon, Vietnam

Ewert Åberg, Head
Department of Plant Husbandry
Agricultural College of Sweden
S-750 07 Uppsala 7, Sweden

James S. Bethel
Dean, College of Forest Resources
University of Washington
Seattle, Washington 98105

Geoffrey E. Blackman, F.R.S.
Department of Forestry
Oxford University
Oxford, England OX1 3RB

Robert F. Chandler, Jr.
Asian Vegetable Research & Development Center - (AVRDC)
P.O. Box 42
Shanhua, Tainan
Taiwan (741)
Republic of China

William B. Drew
Department of Botany & Plant Pathology
Michigan State University
East Lansing, Michigan 48824

F. Clarke Fraser
Department of Biology
McGill University and Montreal Childrens' Hospital
Montreal, Quebec, Canada

John D. Fryer, Director
Weed Research Organization
(Agricultural Research Council)
Begbroke Hill, Sandy Lane, Yarnton
Oxford, England OX5 1PF

Frank B. Golley, Jr.
Executive Director
Institute of Ecology, The Rockhouse
University of Georgia
Athens, Georgia 30601

Phạm-Hoàng-Hộ
Department of Botany
Faculty of Science
227 Cong-hoa Street
B.P. A-2
Saigon, Vietnam

Peter Kunstadter
Department of Epidemiology
University of Washington
Seattle, Washington 98195

Alexander H. Leighton
Head, Department of Behavioral Sciences
Harvard School of Public Health
55 Shattuck Street
Boston, Massachusetts 02115

Howard T. Odum
Department of Environmental Engineering
University of Florida
Gainesville, Florida 32601

Paul W. Richards, C.B.E.
School of Plant Biology
University College of North Wales
Bangor, Caernarvonshire, Wales, U.K.

Fred H. Tschirley
Pesticides Coordinator
U.S. Department of Agriculture
Office of the Secretary
Washington, D. C. 20250

Paul J. Zinke
School of Forestry & Conservation
University of California
Berkeley, California 94720

NAS/NRC Staff

Philip Ross, Executive Secretary
Joseph M. Carrier, Staff Officer
Selma P. Baron, Administrative Secretary
Christina C. Stephens, Secretary

NAS/NRC Research Associates

Jeary Adrian Glenn
Neil L. Jamieson, III
Gary D. Murfin
A. Terry Rambo

Consultants to the Committee on the Effects of Herbicides in Vietnam

Paul T. Baker
Department of Anthropology
Pennsylvania State University
University Park, Pa. 16802

Steven J. Berman
Assistant Professor of Tropical Medicine
University of Hawaii
Leahi Hospital
3675 Kilauea Avenue
Honolulu, Hawaii 96816

Arthur A. Breitsprecher
College of Forest Resources
University of Washington
Seattle, Washington 98195

Pham-hồng-Chủờng
National Agricultural Institute
45 Cường Đe Street
Saigon, Vietnam

George M. Davis
Associate Curator of Malacology
The Academy of Natural Sciences
19th & The Parkway
Philadelphia, Pa. 19103

Robert Desowitz
Professor of Tropical Medicine
University of Hawaii
Leahi Hospital
3675 Kilauea Avenue
Honolulu, Hawaii 96816

Donald P. de Sylva
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

Duane J. Gubler
Assistant Professor of Tropical Medicine
University of Hawaii
Leahi Hospital
3675 Kilauea Avenue
Honolulu, Hawaii 96816

Roger T. Hanlon
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

Chamlong Harinasuta
Dean, Bangkok School of Tropical Medicine
Bangkok, Thailand

William H. Hatheway
College of Forest Resources
University of Washington
Seattle, Washington 98195

Gerald C. Hickey
Southeast Asia Program
Cornell University
Ithaca, New York 14850

Raymond F. Hixon
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

LeRoy Jones
30 Irving Street, Apt. 43
Cambridge, Massachusetts 02138

Edward B. Knipling
U.S. Department of Agriculture, ARS
P.O. Box 225
Stoneville, Mississippi 38776

Alan E. Krusinger
U.S. Army Engineer Topographic Laboratories
Geographic Sciences Laboratory
Fort Belvoir, Virginia 22060

James Low
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

Jane M. Murphy
Associate Professor of Anthropology
Department of Behavioral Sciences
Harvard School of Public Health
55 Shattuck Street
Boston, Massachusetts 02115

Michael Newton
Associate Professor, Forest Ecology
School of Forestry
Oregon State University
Corvallis, Oregon 97331

Harding B. Owre (Michel)
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

Nguyen-Khoa Phon-Anh
The Center for Vietnamese Studies
212-A, Tran Hung-Dao Boulevard
Saigon 2, Vietnam

Warren C. Robinson
c/o Population Council
P.O. Box 2-75
Bangkok 2, Thailand

Sanga Sabhasri
Secretary General, National Research Council of Thailand
Bangkok, Thailand

Howard J. Teas
Biology Department
University of Miami
P.O. Box 9118
Coral Gables, Florida 33124

William L. Thomas
Department of Geography
California State University
Hayward, California 94542

Robert C. Trumbull
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

Luong Tan Tuoc
Department of Forestry
National Agricultural Center
45 Cuong De Street
Saigon, Vietnam

Kenneth J. Turnbull
College of Forest Resources
University of Washington
Seattle, Washington 98105

Charles P. Weatherspoon
U.S. Army Engineer Topographic Laboratories
Geographic Sciences Laboratory
Fort Belvoir, Virginia 22060

Bernard J. Yokel
University of Miami
School of Marine & Atmospheric Sciences
10 Rickenbacker Causeway
Miami, Florida 33149

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

The Effects of Herbicides in South Vietnam

SUMMARY

Origin of the Study (Section I)[a]

The study had its origin in the widespread public concern that the extensive use of herbicides in the Vietnam war may have had serious adverse effects, perhaps irreversible, on environment and people, major economic losses because of damage to forests and crops, and reproductive failures, congenital malformations, and genetic damage in humans.

In response to this public concern, Congress in late 1970 directed the Department of Defense (DOD) to contract with the National Academy of Sciences (NAS), for a study of the ecological and physiological effects of the widespread military use of herbicides in South Vietnam (SVN). A 17-member committee, with additional professional staff and 30 consultants, carried out the study, which included field, laboratory, and library research. Some 1,500 man-days were spent in SVN during the course of the study, the results of which are discussed in the following report. Additional technical details are available in the public records of the Committee.

The Committee conducted work on the following:

1. Inventory of the sprayed areas by herbicide type, date, and frequency of spray application as related to vegetation types and to population density.

2. Effects on vegetation, with emphasis on the inland and mangrove forests--the two vegetation types subjected to the most extensive herbicide spraying--and also with consideration of effects on crop production.

3. Persistence of herbicides in the soil, and their effects on soil fertility, i.e., on the content of essential nutrients available to plants.

4. Effects on animals (limited to studies on animal populations in estuaries, and on the populations of disease vectors, both in the mangrove).

5. Effects on people (medical, socioeconomic, psychological).

The extent to which these problems could be effectively dealt with was highly variable. The Committee could construct only a tentative initial program; this had to be modified repeatedly in the course of the work. The principal limitation to the Committee's work was the security conditions in SVN, which rendered long-term field studies virtually

[a] Section numbers refer to sections in the body of this report.

impossible. Moreover, the Committee started its work in SVN in September 1971, while all major herbicide operations were terminated early in that year; the Committee had somewhat over one year for gathering most of its materials. Hence, on the one hand, relatively short-term effects were difficult to study; on the other hand, except where detailed historical information such as aerial photographs were available, research was limited to short periods of time, whereas some of the effects, for example on succession of vegetation in forests, are long-term ones. Statistics and inventories on SVN population, forestry, and agriculture were not available or did not contain sufficient detail to allow quantitative assessments of many herbicide effects, particularly at the national level. Despite these limitations, we carried out field studies on a number of problems (effects on vegetation and soils, persistence of herbicides in soils, effects on estuarine life and on ecological-epidemiological effects of defoliation, and on the perception of herbicides and their effects by humans), and the available documents, including extensive aerial photography, were examined and evaluated.

<u>History of Military Use of Herbicides in South Vietnam</u> (Section II B)

The military use of herbicides in SVN began in 1962, was greatly expanded in 1965 and 1966, and reached a peak in 1967-69 (see Table I). After it was reported that 2,4,5-T, one of the components of the most extensively used herbicide preparation, Agent Orange, caused birth defects in mice, the use of this agent was stopped in 1970, and, during 1971, application of herbicides under U.S. military control was rapidly phased out. According to records available to the Committee, fixed-wing operations ceased in 1971, and other applications in October of that year. The herbicide agents used in the Vietnam war and the application rates are shown in Table II.

<u>The Herbicides Used in the Vietnam War</u> (Section II C)

The herbicides used for military purposes in SVN are among a considerable number of chemical compounds utilized widely for the control of weeds and unwanted vegetation, although the application of some of them, in the United States and some other countries, is limited to specific purposes. They are selected because they can be manufactured cheaply and in large quantities, but also for physical, chemical, and biological characteristics that minimize undesired side effects. They have been used worldwide in large quantities, on the whole without causing serious hazards. There is considerable information on their properties, such as solubility and volatility, effects on plants, behavior in soil, toxicity on and behavior in animals, although the amount of this information is greater for some (2,4-D and 2,4,5-T) than for others (picloram, cacodylic acid).

In the form present in Agent Orange, 2,4-D and 2,4,5-T are little soluble in water but are moderately volatile. In soil, they undergo rapid breakdown (2,4-D more rapidly than 2,4,5-T). These properties indicate that the two compounds will not readily move in soil and water, though some movement as vapor does occur. 2,4-D in the form present in Agent White and the other component of this agent, picloram, are non-volatile

Table I.

Application of Herbicides in the Vietnam War by Year

Millions of Gallons

Year	1962-July 1965	Aug-Dec 1965	1966	1967	1968	1969	1970	1971	Total
Orange	NA[a]	.37	1.64	3.17	2.22	3.25	.57	.00	11.22
White	NA[a]	0	.53	1.33	2.13	1.02	.22	.01	5.24
Blue	NA[a]	0	.02	.38	.28	.26	.18	.00	1.12
Total	1.27	.37	2.19	4.88	4.63	4.53	.97	.01	18.85

[a]Not available.

Table II.

Herbicides Used in SVN 1965-1971

Agent	Active Chemical Components	Military Application Rate (lb/acre)	Millions of gallons used, Aug. 1965-1971
Orange	2,4-D 2,4,5-T	12.00 13.80	11.22
White	2,4-D Picloram	6.00 1.62	5.24
Blue	Cacodylic acid	9.30	1.12
Total			17.58

but highly water-soluble, and picloram is more persistent in soil than 2,4-D or 2,4,5-T. Thus, while there is no hazard of movement in vapor form, there is some hazard of movement with water, both in soil and by rain. Cacodylic acid, the active component of Agent Blue, is also non-volatile and water-soluble but decomposes rather rapidly to non-soluble, relatively non-toxic aresenical compounds in soil and water.

2,4-D, 2,4,5-T, picloram, and cacodylic acid are distinctly toxic but only when ingested or absorbed in relatively large amounts. The toxicity of 2,4-D and 2,4,5-T is somewhat greater than that of picloram and cacodylic acid. 2,4-D and 2,4,5-T are rapidly excreted in unchanged form by most animals, and there is no evidence for accumulation in any tissues or in the food chain. Some derivatives of the two herbicides, including those present in Agent Orange, seem, however, to possess a relatively high toxicity for some aquatic animals.

In 1969, both 2,4-D and 2,4,5-T were reported to produce birth defects in laboratory animals. At about the same time, it was recognized that 2,4,5-T contained a contaminant, TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin), an extremely toxic material that also possessed teratogenic properties. However, whereas some of the birth defects in laboratory animals, which had originally been ascribed to 2,4,5-T, were actually caused by TCDD, it appears that 2,4,5-T has some teratogenic potential of its own, although at relatively high doses. Tests with 2,4-D were less conclusive.

<u>TCDD, a Contaminant of 2,4,5-T</u> (Section II C-2, C-5)

TCDD is extremely toxic to some laboratory animals. In male guinea pigs, the most sensitive animal so far found, a single dose of 0.0006 milligrams per kilogram body weight causes death in half of the animals fed. In other animals (rats, mice, rabbits) the corresponding dose is considerably higher, in the range of 0.05 to 0.2 milligrams per kilogram. TCDD has been found to be teratogenic in mice; results with other laboratory animals have not been conclusive. The lethal dose in humans is not known, nor is that required to cause birth defects, if indeed there is such an activity. TCDD is strongly implicated as the main cause of chloracne, a disease that has affected employees in some plants manufacturing 2,4,5-T or its precursor, 2,4,5-trichlorophenol. TCDD apparently decays very slowly under normal environmental conditions, indicating that its potential hazards may be very persistent.

<u>Inventory of the Military Use of Herbicides in South Vietnam</u> (Section III)

The Committee conducted as thorough as possible an inventory of the herbicide operations in SVN, as the basis for assessing the effects of these operations on vegetation, soils, and people. The main source used was the HERBS tape, a computerized record of time, place, amount, type, and military purpose of herbicide operations carried out by aircraft between August 1965 and February 1971 (plus a printout covering the period

March through October 1971, the stated termination of the U.S.-controlled herbicide operations). The material, which covers about 85 percent of all herbicide operations in SVN, was evaluated in conjunction with the help of a vegetation map and aerial photographs in order to determine the distribution of herbicides with respect to vegetation types. Their distribution with respect to population and to settlement types in the whole country could not be studied, because relevant material was received too late. Results of such studies in selected areas are summarized under "Human Reactions to Military Use of Herbicides," Items 1-3, see below.

The number of gallons sprayed in SVN is shown in Tables I and II, the areas sprayed once, twice, and more times in Table III. The total area of SVN that was sprayed is somewhat larger than the area of Connecticut, while the entire country (approximately 44.6 million acres) equals in size this state plus Rhode Island, Maine, Vermont, New Hampshire and Massachusetts.

About 88 percent of the herbicide missions recorded on the HERBS tape were designated for defoliation, about 9 percent were for crop destruction, and the remaining 3 percent were directed at base perimeters, enemy cache sites, waterways, and lines of communication. There was little relationship between recorded purpose and distribution of sprays with respect to native vegetation type, although a relatively greater proportion of the crop-destruction missions employed Agent Blue, and all these missions were flown in the northern two thirds of SVN. Regardless of the stated purpose of the mission, about three quarters of the total gallonage was sprayed over inland forests, about 8 percent over mangrove forests, and a little over 7 percent over permanently cultivated areas (see Table III). Crops were affected, however, to a greater extent than indicated by the latter figure because temporary fields ("swiddens") such as those customarily cultivated by the Highlanders (Montagnards) were classed as "forest," and because field crops were damaged by drift of herbicides outside the intended or recorded spray path.

Herbicide Damage to Vegetation (Section IV)

Death of and damage to vegetation caused by herbicides can have many different consequences: loss of potential production at a stage before the growth becomes economically valuable; loss of commercial products such as timber, grain and fruit; lack of young plants and of seeds necessary to maintain the "system," the latter type of effect being particularly important in native vegetation. The Committee studied herbicide damage to three major vegetation types of SVN: the inland forest, the mangrove forest, and (permanently) cultivated land. Information on effects on the last-named type (crop damage) was obtained mainly in a study of effects on settlements and by interviews with villagers, and the results are therefore reported under "Effects of Herbicides on Humans." With the exception of extensively sprayed mangrove forests, aerial photographs showed that vegetation cover of some type returned to most areas within six months to a year after they had been sprayed. Because of limited access to the

Table III.

Estimated Acreage Sprayed One or More Times, 1965-1971[a]

Vegetation Type[b]	Total in SVN in 1953		Number of Times Sprayed Aug. 1965-Mar. 1971				Total Sprayed one or more times	
	Millions of acres	Percent	Millions of acres				Millions of acres	Percent
			1	2	3	4+		
Inland forest	25.91	62.4	1.72	0.62	0.22	.11	2.67	10.3
Cultivated land	7.80	18.8	0.20	0.04	0.01	0.00	0.26	3.2
Mangrove forest	.72	1.7	0.14	0.07	0.03	0.02	0.26	36.1
Other	7.07	17.1	0.31	0.07	0.02	0.00	0.39	5.5
Total	41.50	100.0	2.37	0.80	0.28	0.13	3.58	8.6

[a]Does not include coverage of missions before August 1965 (1.27 million gallons) and missions after that date for which location information is incomplete (1.1 million gallons), representing about 12.5% of the total gallonage accounted for. Compare Tables III C-1 and III C-2, and related text.

[b]Inland forests include those areas classed as dense forest, secondary forest, swidden zones, bamboo forests, open dipterocarp, Lagerstroemia and Leguminosae forests. "Other" include pine forests, savanna and degraded forests, grasslands and steppes in higher elevations, dunes and brushland, grass and sedge swamps and areas of no vegetation (urban areas, roads, water courses, etc.). Classification and area figures follow Bernard Rollet (1962). See Tables II-E and III B-3 and the accompanying text.

forest we were often not able to determine the exact nature of the post-spray vegetation. The fact that vegetation of some type generally returned promptly suggests, however, that there was no permanent inhibition of plant growth because of adverse conditions in the soil.

Inland Forests: Damage and Redevelopment (Section IV B[1],[2])

The inland forests received three-quarters of all herbicide sprays. As a result of extensive study of aerial photography and limited observations on the ground in sprayed forests, we conclude that damage to forests depended on the frequency with which a given area was sprayed, the time intervals of individual sprays in multiple-sprayed areas, the extent to which there was other disturbance (especially bombing, and also clearing and burning for agriculture or other purposes, as well as selective logging). It should also be noted that much of the inland forests of SVN, including the areas sprayed with herbicides, was already disturbed--as are most tropical forests, except those in the remotest locations--by lumbering, agriculture clearing, or fire prior to the time of spraying. Although some areas are technically classed as "forest," and have been subjected to herbicide sprays, they contained few large trees.

Because so many variables are involved, the extent to which there will be recovery from deleterious effects, and the time required, cannot be stated in precise terms. In some areas, particularly those sprayed only once and not subject to other disturbances, damage was generally limited to the tallest trees, which were more exposed to the spray than lower ones. It appears that redevelopment will resemble the pattern of forest growth following harvest of large trees. In areas sprayed more frequently, where damage was heavier in the lower stories of the forest, the redevelopment will take longer. If large-scale rehabilitation of war-damaged inland forest is undertaken, it is probable that all single-sprayed and most multiple-sprayed forests can eventually be restored to productive forestry by adopting appropriate silvicultural practices. Systematic on-the-ground studies of sprayed areas are essential, with special attention to numbers and sizes of young individuals of the important tree species and of seed sources.

Concern has been expressed that herbicide-damaged forests will be replaced by bamboo. Information derived from limited field and aerial reconnaissance suggests that where herbicide spraying has led to the death of the forest tree species and suppression of their reproduction, bamboos, if present in the area--as they are in many but not all inland forest areas--tend to increase with establishment of pure stands, which may persist for many years. However, it is difficult to distinguish this herbicide effect from effects of other disturbances, particularly fire and agricultural clearing, and it should be realized that extensive bamboo forests existed in the SVN before the herbicide operations, probably as results of such disturbances. Evidence for rapid invasion of new forest areas by bamboos as a consequence of herbicide spraying was not observed.

Inland Forests: Loss of Merchantable Timber and Other Damage (Section IV B-3)

Using the HERBS records of herbicide operations, plus aerial photographs taken before, during, and after these operations, combined with information on the characteristics of the forests of SVN and measures of logs used currently in sawmills in SVN, the Committee estimated the total loss of merchantable timber in SVN forests by estimating the total number of trees of merchantable size killed by the herbicide operations in the inland forests of SVN, based on a detailed analysis of no less than some 100,000 acres (40,000 hectares). The estimate is 1.25 million m^3 with a range of 0.5 to 2.0 million m^3. This may be related to an estimated total of about 8.5 million m^3 of merchantable timber in the sprayed area. Our estimate is, however, much lower than previous estimates by some other authors. The reasons for this discrepancy lie in differences in assumptions about the status of the forest inventory in SVN prior to application of herbicides, in estimates of effect of one and more than one spray, in predictions of length of time for restoration of forest structure following spray, and differences in estimates of total forest area exposed to herbicide sprays.

Loss to non-merchantable timber in the herbicide-sprayed area of the inland forests was estimated to be between 5,050,000 and 11,150,000 m^3 (see Table IV B-8) although the accuracy of this estimate is considerably less than that for merchantable timber.

In addition to the losses in merchantable and non-merchantable timber, there are other types of damage; to saplings and young trees ("growing stock"), which in normal forest development will replace older trees as these die or are harvested, to growth because of herbicide damage (e.g., loss of part of the crown), which however did not result in death, and to seed sources. These damage classes could not be determined quantitatively, because of lack of both access on the ground and a forest inventory. However, the damage to growing stock has been substantial, particularly in heavily overused open forests and in young forests emerging from abandoned swidden. Loss of seed sources in these forests may also be a very critical type of damage, with serious consequences for the future of the forests, even though the merchantable volume of the source trees (per unit forest surface) was quite small. Thus, the total damage, particularly in multiple-sprayed inland forest areas, was undoubtedly extensive and serious. We also found some, although not very extensive, anomalies for which the explanation is not clear. These were usually areas that had been sprayed four times and from which the tree cover has almost entirely disappeared. The reasons for this could not be determined. Other areas sprayed as many or more times did not exhibit this much damage.

Damage to the inland forests was not confined to herbicides. Damage by bombing was also heavy, in both extent (area) and intensity (destruction of all trees, large and small, in the area of the crater, heavy damage in its perimeter, including metal fragments embedded in surviving trees, which pose a hazard in sawmills, etc., and may reduce the value of timber from SVN in general).

Damage and Regrowth in Mangrove Forests (Section IV C)

A large proportion of the mangrove forests was sprayed with herbicides, and was more heavily affected by the spraying than any other vegetation type in SVN. Of the approximately 720,000 acres of SVN that were covered by mangrove (representing about 1.7 percent of the total area of the nation), about 260,000 acres, or 36 percent, were sprayed. One spray usually killed all mangrove trees; large contiguous areas were devastated, and there has been little or no recolonization of mangrove trees in extensive sprayed areas, except along the margins of some of the canals that drain these swamps. One reason for this is that in some areas, especially the "Rung Sat Special Zone" southeast of Saigon, the destruction of this vegetation type was so complete as to eliminate most seed sources. Wood cutting, a traditional economic pursuit in the mangrove forests, is probably further reducing the supply of seeds and retarding recovery. An estimate based on a model suggests that, under present conditions of use and natural regrowth, it may take well over 100 years for the mangrove area to be reforested. With a massive reforestation program, the forest could probably be restored in approximately 20 years if sufficient money and seed resources were available.

The mangrove forest plays important roles as spawning site and food source for many economically important fish and shellfish species. Comparative studies of frequency of fish, shellfish, and planktonic organisms--the last-named important as food for the former two--in waters of an herbicide sprayed and largely denuded region and of an intact mangrove region showed that, while both were rich in planktonic organisms, the numbers and variety of these organisms were lower in the former than the latter. The same was true of large fish, while fish eggs and larvae were more frequent in the denuded region, although the variety of fish was the same. However, the data are not extensive, and the differences between the two sites are not large enough to draw firm conclusions. Overall fish catch in SVN has not changed much in the years of the herbicide operations, but catch per fishing craft (per unit of effort) has declined, in contrast, for example, to the situation in Taiwan and Thailand. However, it was not possible to separate the operation of herbicide-related effects, such as the possible decrease in fish food, from other effects, such as increased fishing pressure, increased motor boat traffic, and decreased safety.

<u>Effects of Herbicides on Soils</u> (Section V)

The Committee conducted two kinds of studies to investigate the possibility that military applications of herbicides might have resulted in long lasting changes in the ability of the soil to support plant growth. First, samples of soil from sites in SVN and Thailand that had been sprayed during the military herbicide operations or in related tests were chemically analyzed for the presence of herbicides (2,4,5-T; 2,4-D; picloram). Second, planting experiments and chemical analyses for residual herbicides were conducted in SVN and the Philippines in tropical forest, agricultural, and mangrove soils that had been treated with herbicides in the same amounts as used in the herbicide operations in SVN. In general, both chemical and biological assays showed that toxic residues of herbicides applied at military rates disappeared within less than one year. If traces persisted (in certain mangrove areas), they were below or near the limit of biological activity even in highly sensitive plants and did not seem to affect the reestablishment of native vegetation.

Limited studies were made of soil fertility--that is, the contents of the soil in readily available essential plant nutrients--in herbicide sprayed and unsprayed inland and mangrove forest areas. Compared with other ecosystems, in tropical forests a very high proportion of those plant nutrients is contained in the vegetation, rather than being retained in the soil. Concern has therefore been expressed that the death of large amounts of tropical forest vegetation may lead to loss of essential nutrients from the ecosystem, decreasing the prospects for revegetation after extensive herbicide treatment. Our results indicate, however, that although there were certain differences between "sprayed" and "unsprayed" inland forest and mangrove soils, the widespread death of vegetation caused by the herbicides has not had lasting detrimental effect on those plant nutrients within the ecosystem, with the possible exception of potassium. Potassium may be lost especially if the levels of other elements in the soil or the shed plant matter should become too high.

We saw no evidence in aerial photographs, aerial observation, or our limited visits to affected forests that destruction of vegetation by herbicides had resulted in laterization (permanent hardening of the soil surface, which inhibits forest regrowth) over any large areas of inland forests, as has been suggested by some authors.

<u>Effects of Herbicides on Humans</u> (Section VII)

The following conceivable types of herbicide effects on animals and humans were considered by the Committee: toxicity in directly exposed individuals; birth defects of offspring born to exposed mothers; ecological effects on disease-carrying insects and rodents; economic and behavioral changes associated with herbicide-caused destruction of vegetation; and perception and evaluation of herbicide effects by the Vietnamese public.

Herbicides and Birth Defects (Section VII A-1)

The Committee could find no conclusive evidence of association between exposure to herbicides and birth defects in humans. Available records of two major Saigon hospitals and evaluation of records in a third, as far as they go, showed no consistent pattern of association between rates of congenital malformations and annual amounts of herbicides sprayed. The Committee recognizes however that the material is not adequate for definite conclusions.

The Committee has not yet completed its comparison of herbicide-spray records with the dates and places of birth of children with birth defects who were treated at the Barsky Unit, Cho Ray Hospital, Saigon-Cholon. The Barsky data are probably the best ones that can be obtained in SVN for the study of the problem.

The TCDD Problem in South Vietnam (Section VII A-2)

Analyses of samples of Agent Orange that had been returned from SVN, or had been procured but not shipped to the country, indicate that the amounts of TCDD ranged from less than 0.05 to almost 50 parts per million, with average concentrations in two sets of samples of 1.91 and 2.99 ppm. Over 10 million gallons of Agent Orange were used in SVN, suggesting that perhaps 220 to 360 lb of the TCDD contaminant were released over SVN.

Until early 1973, there were no analytical techniques available with sensitivity and specificity sufficient to detect the extremely small quantities of TCDD likely to be present in the environment. A much more sensitive and specific analytical method for detecting TCDD has recently been developed, and it has been reported that TCDD is present in fish and shellfish collected in 1970 and 1973 in waters of SVN, which drain areas that had been subjected to heavy herbicide sprays during the war. While the significance of this finding is by no means clear, it has raised serious, legitimate concerns for the public health; these concerns will persist as long as the problem is not resolved.

Herbicides and Medical-Ecological Changes (Section VII A-3)

Insect and rodent carriers (vectors and reservoirs) of human diseases are sensitive to small changes in the environment that they may share with humans. The Committee studied differences between vector populations and the prevalence of malaria in human populations living in cleared and uncleared mangrove forests. Malarial mosquitoes were absent and there was no malaria among children living in uncleared mangroves in Thailand. Malaria organisms were found in the blood of 7 percent of children in a herbicide-cleared mangrove area in SVN, where mosquitoes of species known to be capable of transmitting malaria were also found. A mechanically cleared mangrove area in Thailand had malarial mosquitoes, and also had a higher rat population than did uncleared mangrove areas in Thailand. The results of this study led the Committee to conclude that clearing of mangroves by mechanical or chemical means may lead to environmental changes that favor vectors of human diseases. In the cleared mangrove community in SVN, the presence of malaria was probably a consequence also of temporary or permanent migrants from previously malaria-infested areas, and of the development of irrigated agriculture in herbicide-cleared areas that previously had been used for woodcutting and fishing.

Human Reactions to Military Use of Herbicides (Section VII B, C)

The Committee studied human reactions to the military applications of herbicides by interpretation of aerial photographs taken before and after spraying of a variety of land use and settlement types, by interviews, and by examination of relevant local documents where available. Studies of one or more of these kinds were conducted in mangrove forest, irrigated rice, coconut plantation, gardening, and upland crop areas, and among Vietnamese and Montagnard peoples (the latter being interviewed in refugee camps). We also made a study of Saigon newspapers and other publications representative of the urban population. The results of aerial photography, documentary, and interviews were highly consistent, thus reinforcing one another. On the other hand, the opinions obtained in interviews in each community were quite diverse, suggesting that our respondents were usually expressing their own perceptions of herbicides, rather than following propaganda lines of either the government of RVN or the NLF. Following are the main general results:

1. Some communities and agricultural areas of all land-use types that we studied were in the direct path of recorded herbicide missions, many of them repeatedly. However, since the areas were selected because they had been heavily sprayed, these results cannot be used for a quantitative estimate of people thus affected in the country as a whole.

2. Herbicide spraying resulted in the displacement of people from their homes and contributed to the urbanization of SVN. However, major dislocations of human populations that followed herbicide sprays were often associated with other types of aerial or ground military activity. In only one out of 18 areas studied did population and settlements increase over the pre-spray period.

3. Application of herbicides in areas of human habitation resulted in destruction of or damage to crops regardless of the intended military purpose and the herbicide agent used. In 16 out of 18 areas studied, crop damage that had been caused by missions designated as defoliation was greater than that by missions designated as crop destruction. In addition to crop damage because the fields were in the direct flight path of herbicide missions, there was evidence for widespread crop damage by drift, i.e., herbicide carried outside the intended target area by wind, even though herbicide missions were not to be flown when wind velocity exceeded a certain limit.

4. Herbicide exposure of field crops usually resulted in loss of production for no more than one growing season. There was no evidence that crops could not be replanted within one year and less after the last herbicide spray. Fruit trees, especially coconuts, jackfruit, and papaya, suffered more persistent damage, and in some cases were killed, leading to loss of production for several years. Damage reparations--which, however, were intended on a solatium basis--were generally inadequate to pay for the direct damage in a single year, and did not even attempt to pay for lost production beyond the year of the spray, nor for the costs of restoring production. The loss was probably greatest to those farmers who were closest to the margin of subsistence and to those heavily dependent on tree crops.

5. Some individuals in every community in which people were interviewed reported that domestic animals and humans became ill or died after exposure to herbicide sprays, or after eating herbicide-treated plants or drinking contaminated water. Toxic symptoms reported included eye, skin, respiratory, and digestive disturbances. Reports of serious illness and death, especially among children, were more common and consistent among the Montagnards than among the lowland people. No independent medical studies of exposed populations were however in either case available from the time of spraying against which these reports could be confirmed or refuted.

6. Effects of herbicides were preponderantly viewed as deleterious to the livelihoods of the people whose land was sprayed, with the exception of some residents of the mangroves, who thought that defoliation resulted in increased security from the NLF, and also made it easier to clear land for irrigated fields. Woodcutters in this area recognized, however, that their primary resource had been largely eliminated by herbicides.

<u>Psychological Reactions to Herbicides</u> (Section VII B-2)

The study of psychological reactions among South Vietnamese consisted of two types of investigations: (1) measurement of emotional strain and (2) assessment of attitudes about herbicides. Refugees from a rural community which had been heavily sprayed showed a higher level of emotional strain than any other group to which they could be compared. Among them, those who had experienced the larger number of hard knocks of war had more evidence of emotional symptoms than those who were less severely hit. The spraying of herbicides contributed in both a general and specific way to the experiences identified as hard knocks. In regard to attitudes about herbicides, most of the people in the countryside held to the pragmatic belief that herbicides were a bad thing among many bad things that occur in war. In contrast, our study of pro-government and opposition newspapers from Saigon showed that the military herbicide program came to be viewed negatively by people in the cities. Herbicides came to be an emotionally charged symbol standing for many apprehensions and distresses, especially those for which Americans are blamed.

RECOMMENDATIONS

In what follows, the Committee recommends that action be taken in several fields as a consequence of its studies. Our first recommendation, however, is that the Committee's report be translated into Vietnamese. This is because it is the people of Vietnam who must live with the consequences of herbicide use and who must undertake remedial action.

It is also clear that Vietnamese effort to cope with the consequences of herbicide use will require financial and technical support from the United States. This should include the necessary funds, training for Vietnamese workers, the lending of technical and professional personnel as needed, and the supplying of equipment.

TCDD (Dioxin)

In view of the very high toxicity of TCDD (dioxin) to animals, and the presence of this substance in Agent Orange, which was widely used in the herbicide operations in SVN (approximately 10 million gal.), and preliminary reports of TCDD in fish in Vietnam on the one hand, and the lack of any data permitting assessment of TCDD effects on humans on the other, we strongly recommend two actions which should be undertaken simultaneously:

(1) Repeated systematic samplings and analyses of materials from Vietnam to verify the presence of TCDD and determine the level and distribution in human foodstuffs, animals involved in the human food chain, and river, estuarine and sea muds. Such samplings should be started immediately and should be repeated at intervals to follow changes that may occur with time.

(2) Long-term studies to obtain a firmer basis for assessing the potential harmful effects of TCDD on man.

Other Human Health Problems

Reports of Highlanders (Montagnards), in comparison with lowland Vietnamese, on death and illness caused by herbicides are so consistent that despite the lack of medical and toxicological evidence for such effects they cannot be dismissed out of hand and should be followed up as promptly as possible by intensive studies which should include medical and behavioral sciences approaches. Such studies will become possible only after peace has been restored in that area.

We strongly urge prompt evaluation of the data the Committee collected at the Barsky Unit of Cho Ray Hospital (see Section VII A-1) and elsewhere to determine whether or not they indicate a relationship between exposure to herbicides and congenital malformations.

We also strongly urge a comprehensive medical study over time of the approximately 50 Vietnamese men who were heavily exposed as handlers of herbicides in the defoliation program, if they can be located, as compared with an appropriate "control" group.

Where defoliated areas are considered as resettlement sites (or have already been settled by new populations) epidemiological studies are recommended, directed at determining changes in populations of potential disease vectors and taking into consideration possible effects of different land-use types on the spread of disease.

Inland Forests

The inland forest regions contain major resources for the people of SVN. These areas have been subjected to the greatest amount of herbicide spray and to other war damage.

We therefore recommend that a complete inventory of representative samples of the forest be made as soon as possible, with particular attention being paid to reproduction and the young age classes of trees and to changes in forest composition, followed by studies to determine the consequences of war-related damage.

A systematic forest inventory is necessary for developing a basic land-use policy. When such a policy is established it may be appropriate to design specific procedures, for example with regard to conservation of forest reserves, for systematic reforestation programs. Forest utilization problems related to war-caused damage should be studied. In heavily damaged inland forest areas, plans and rehabilitation efforts should be initiated as soon as possible.

Mangrove Forests

The mangrove forests of SVN, which are economically important as a source of fuel and of food for fish, have suffered a greater damage than any other type of vegetation in SVN.

Since good inventories have been made of the mangrove forests, the first essential step appears to be the development of a land-use policy which, among other matters, would help determine how much of the mangrove area should be reforested and how much developed for agricultural and other uses. Both developments appear feasible although either one will undoubtedly require a considerable input of labor and capital. The Committee urges most serious consideration of the important role of mangroves as fish and shellfish breeding grounds which require the preservation or reestablishment of adequate forested areas.

Urgent attention should be given to proper utilization of mangrove forests, particularly in view of the increasing energy problems, and the possible need for more fuel in the future.

Records

Many records of the lower reporting levels (district, province) which would have been useful in answering in more detail the direct and indirect effects on agriculture or on movement or health of people were routinely destroyed after being summarized and forwarded to regional or national headquarters. We recommend the preservation of all remaining records relating to herbicide operations. These should be declassified where necessary and made available for further study. Records of this NAS Committee, including data bank, photographs, and other records, should likewise be preserved and kept available for later studies.

General Recommendations

Herbicides are an example of a modern technology which when employed on a massive scale for military use cannot be completely controlled, nor limited in time and space to their intended target. The Committee recommends that Congress, in appropriating funds for development and use of materials and equipment as weapons, also appropriate funds for independent study and monitoring in those cases where there is a serious possibility of any widespread or persistent ecological or physiological effects. The Committee's work is a convincing demonstration of how difficult it is to do this after the fact.

Herbicides were a grave concern to many Vietnamese and achieved symbolic and emotional significance which sometimes outweighed the actual facts. We recommend further studies in collaboration with the Vietnamese with a view to promoting greater understanding of the properties of these herbicides, of their peaceful uses, and their hazards.

Herbicides have been only one of the impacts of the recent war on the Vietnamese people. The various direct and indirect war impacts were however all closely interrelated, and it is the Committee's firm belief that rehabilitation and reconstruction efforts should not be fragmented according to different categories of damage but should proceed in an integrated fashion, and that such efforts be undertaken as rapidly as conditions permit.

We are aware of the complex and difficult nature of some of these recommendations, but we urge that the work here recommended be initiated promptly, since any delay will make its accomplishment more difficult.

I. INTRODUCTION

A. Origin of the Study

The study had its origin in the concern of many people in the United States and elsewhere in the world about potential adverse effects of the widespread use of herbicides in the military effort in South Vietnam. Although for many years very large quantities of herbicides have been used successfully and safely for controlling weeds in agriculture, industry, and the home garden, never before had herbicides been used in such heavy doses on such areas of natural vegetation as in the war in SVN.

Among the concerns voiced by the public were such questions as:

Had the extensive use of herbicides modified the environment of Vietnam beyond the point of recovery?

Had the damage to forest and crops caused major economic loss?

Was there evidence for an association between exposure to herbicides and human reproductive failures, congenital malformations, and genetic damage?

The study was authorized by an Act of Congress, Public Law 91-441, the Fiscal Year 1971 Military Procurement Authorization Act. Section 506(c) of this law directed the Secretary of Defense to "undertake to enter into appropriate arrangements with the National Academy of Sciences to conduct a comprehensive study and investigation to determine (A) the ecological and physiological dangers inherent in the use of herbicides, and (B) the ecological and physiological effects of the defoliation program carried out by the Department of Defense in South Vietnam." Pursuant to this law, the Committee on the Effects of Herbicides in Vietnam was established under a contract between NAS and DOD, signed December 8, 1970. The date for submission of a report to DOD, to be followed by transmission to Congress within a month, was originally January 31, 1972, and this was later extended to December 31, 1973.

The Committee was formed in June 1971, and several members joined at later dates. The Committee membership, and NAS Staff and Research Associates are listed on p. xxi-xxii and Consultants on p. xxiii-xxiv. The first meeting was held July 7-9 of the same year, and the first visit to SVN (and Thailand) was made in September-October. The last Committee member to visit SVN left the country in September 1973. Altogether, Committee personnel spent over 1500 man-days in SVN.

B. Scope and Limitations of the Study

(1) Definitions

Because of the very broad objectives laid down in PL 91-441 on the one hand, and the limited time available for the study on the other, it was necessary to delimit the scope of the studies, and agreement was reached in consultation with members of Congress that the study be directed primarily at the consequences of the military use of herbicides in SVN. Supporting work was carried out in Thailand and the Philippines because some of the investigations could not be undertaken in SVN due to security problems.

PL 91-441 calls for studies of the ecological and physiological effects of herbicides. By physiological we mean the effects on the function of individual organisms (although in the study of such effects, it is usually necessary to employ groups of similar organisms, so-called populations). By ecological we mean effects on "ecosystems," that is communities of various organisms and their patterned interactions with one another and with other parts of the environment.

Effects of herbicides may be direct and indirect. The most common direct effect is that implied by the name of these chemicals, that is, death or failure of growth and reproduction of a treated plant. Other possible direct effects might include toxicity to animals and man. Indirect effects operate through a chain of events initiated or exacerbated by the direct effects of the herbicide, and may be very diverse. If crops are killed by herbicides, people will not only be deprived of food, but their entire economic situation may be profoundly altered. If productivity of a forest is retarded by spraying with a herbicide, the woodcutter working in that forest may lose his income and be forced to move to another region or to seek another employment. The greatest complexity of indirect effects can be predicted in the realm of ecological responses. Ecosystems are generally characterized by a very finely attuned balance between their living components (animals, plants, microorganisms) and between these and the physical environment (soil, water, microclimate). Moreover, even relatively undisturbed ecosystems are very often not static but are changing slowly but in a definite sequence ("succession") leading to a so-called "climax," the final stage that, if undisturbed, will not undergo further changes in the absence of environmental changes. Injury to, or death of one component as the result of herbicidal treatment or other disturbances is thus apt not only to disturb the system as such, but may also affect its further evolution, that is, the effects may last over prolonged periods of time. This holds not only for natural ecosystems but may involve or affect man, too. Thus, a change in the floral composition of a forest as a result of herbicide treatment may involve changes in the distribution of animals (insects, rats) that function as vectors of human diseases, resulting in changes in the incidence of these diseases in adjacent settlements even if these latter were not directly affected by the herbicide.

(2) Selection of Objectives

With the complexities briefly discussed in the preceding section, it was apparent that the research design would be complex and time-consuming. It was therefore necessary to delimit the studies, focusing on work which promised to yield as high a return as possible in terms of understanding herbicide effects and their repair. From the inception of its work, the Committee agreed that it should address the following broad problems, as these represent the most important and also include the most sensitive issues which have been raised in the public mind by the use of herbicides in the Vietnam war:

1. Inventory of the sprayed areas by herbicide type, date, and frequency of spray application as related to vegetation, soil type, and population density.

2. Effects on vegetation, with emphasis on the inland and mangrove forests--the two vegetation types subjected to the most extensive herbicide spraying--but also with consideration of effects on crop production.

3. Persistence of herbicides in the soil, and other effects on soils.

4. Effects on animals.

5. Effects on people (medical, socioeconomic, psychological).

6. Impact on the country as a whole.

An inventory of the sprayed areas appeared important per se, in order to know the actual extent of the military use of herbicides in SVN in both space and time. Above and beyond that, however, it is clear that the kind and intensity of herbicide effects would depend not only on the characteristics and the distribution of the herbicides themselves, but equally on the characteristics of the geography, natural vegetation, human population and land use in the sprayed areas. The Committee planned, therefore, to use the inventory as an important and, in many cases, as the prime basis for assessing herbicide effects on inland and mangrove forests, on crop lands, soils, animals and humans. For example, regarding forests we hoped both to estimate the direct damage and to evaluate longer term effects (speed and character of recovery); regarding humans we intended to relate the herbicide effects to the density and patterns of population and the types of land use, taking into consideration changes in these characteristics effected by the herbicides themselves and by other war-related or unrelated events, such as voluntary or enforced relocation of people.

(3) Results and Limitations

The extent to which these objectives were achieved has been very variable. We believe that, within limits which will be discussed, we obtained a comprehensive and reasonably accurate inventory of the herbicide sprays and their relation to vegetation types. We were able to assess certain kinds of damage in inland and mangrove forests--in the former, losses in merchantable timber; in the latter, the extent of kill of the vegetation--but our studies on longer term changes have remained quite fragmentary.

Regarding effects on crops, the Committee conducted interviews with American and Vietnamese officials and with Vietnamese villagers, reviewed records, and analyzed aerial photographs for relationships between land-use patterns and herbicide missions. A small study was conducted of the so-called crop destruction missions, using herbicide spray records and aerial photography. The analysis of aerial photographs showed clearly that agricultural land and settlements had been sprayed with herbicides, irrespective of the stated military objective, and that annual crops and fruit trees had been destroyed or damaged. It was however not possible to make a quantitative assessment of crop damage.

Experimental studies on soils which we conducted indicated that herbicides were not persistent for long periods, and that herbicide-induced changes in soil fertility have not reached proportions which would make them a limiting factor in revegetation. We tabulated soil types as related to vegetation and land-use types, but because of restricted access for field studies we were unable to make use of this information in studies of herbicide effects.

Direct observation of animals was limited to two specific studies, namely, comparing populations of potential disease vectors and of aquatic organisms in sprayed (or otherwise denuded) and intact parts of mangrove forests. An increase in mosquito vectors of malaria was demonstrated as was a reduction in yield of fish per fishing boat. The change in mosquito vector populations is probably related to changes in human activities (rice farming) in addition to the ecological effects of herbicides. The reasons for the decrease in fish yields are not known.

It was not possible to relate in general the distribution of herbicide sprays to population and changes of population distribution during the war in SVN.

Work on direct medical effects in humans was concerned with possible teratological and reproductive effects. It consisted, firstly, in examining existing pertinent information, and secondly of a pilot study in which the records of one hospital unit that had treated a large number of patients with birth defects were examined. Work on socioeconomic and psychological effects was conducted in selected populations in various parts of the country. One study dealt with effects of herbicide sprays on settlements of different types, as apparent in aerial photography. Two other studies--one mainly on lowland Vietnamese, the other on the Highlanders (Montagnards)--were based on interviews and where available supporting documentations and information.

The reasons for the limitations in our work were (1) the passage of time between the end of the extensive military herbicide missions and the beginning of our studies; (2) limitations in time, funds, and personnel; (3) lack of or deficiences in important background material (inventories, records); and (4) the security situation in SVN. The time lapse between the end of massive herbicide application by fixed-wing aircraft in early 1970 and the first visit of the Committee to SVN (September-October 1971) was enough to render studies of relatively short-term herbicide effects on soils, crops, animals and people a difficult task. Some gaps (studies on herbicide persistence) could be closed by experimental work carried out by the Committee; others, however, could not.

The time limits for our whole effort (two years between constitution of the Committee and delivery of the final report; little more than one year for field work and data gathering) limited the extent of many phases of the studies, but were most serious for studies of possible reproductive and teratological effects in humans. It may be recalled that in the case of the Atomic Bomb Casualty Commission in Japan, the work of which pursued objectives comparable to this part of our study, it took one year of organization and five years of actual work to obtain major data, and work is still continuing.

Reproductive and teratological effects of herbicides in SVN were considerably more difficult to study than effects of atomic radiation. One reason is there was no single point source so dosage of individuals in the exposed populations is difficult to estimate. Other difficulties in studying the effects were the absence of adequate baseline data on the population of SVN, and extremely limited work on the toxicology of some of these substances in humans. Lack of background material was felt in many phases of our work: no adequate inventories were available on inland forests and on animals, and records on crops and on humans were incomplete. The lack of security, however, was that limiting factor which pervaded most of the phases of our work. Thus, it was possible to make only very limited on-site observations and studies in the inland forests which represent the largest single vegetation type of the country and some of which have been subjected to extensive and repeated herbicide sprays, and to determine extent and nature of their recovery in any comprehensive and quantitative manner. This applies equally to the studies of the Highlanders since they may have suffered, directly or indirectly, from the military use of herbicides more than any other population group in SVN. Some of these limitations will be mentioned in later parts of the report, in relation to specific problems. The limitations necessitated many changes in the detailed work plans; one major consequence was that photo-interpretation was used to a much larger extent than originally envisaged.

(4) Organization of the Report

The present report is an account of the main results of the Committee's work. The objectives of the Committee required that the investigations draw on several scientific disciplines. Thus, a division of labor was inherent in our charge, and work was organized so that scientists of a common or related orientation worked together as subunits of the Committee, addressing questions appropriate to their training and experience. Although the Committee as a whole submits this report as a joint product, the organization of this document reflects the division of responsibility upon which the investigations were built, with each unit using the language, theory, and methods of its particular problem area. In an effort to provide clarity and continuity, some editorial links have been prepared to link the separate sections. These comments, however, are not meant to imply that the organization was rigid. Several Committee members were involved in work on several different problems, reflecting the fact that there were important interrelations between all the problems that were studied, e.g., between herbicide persistence (or the lack thereof) in soil and persistence of effects on the vegetation, or between effects on vegetation and effects on the people. The individual chapters or sections of the report have been drafted by the people who did the work, or under whose direction the work was done. The editorial links and cross-references have been prepared mainly by the Chairman. However, all parts of the report have been read by all Committee members, and their comments considered so as to have as much agreement as possible.

The literature references in this part of the report are selective, and more are given for subjects and problems about which relatively little is known or which are still subject to dispute than for well-established and widely accepted matters.

Details of many parts of the study are available as working papers which formed the basis from which this report was prepared.

C. Committee Policies

The work of the Committee has been limited to the objectives stated in Section 506(c) of Public Law 91-441, that is, the physiological and ecological effects of the herbicides used in the Vietnam war. Explicit political conclusions and judgments have been excluded. For example, we could and did ask what effects the use of herbicides had on mangroves and whether these effects would persist. We might have asked whether mangroves which were destroyed by herbicide sprays should be restored by artificial reforestation, or whether former mangrove land should be developed for agriculture. However, we feel that judgment on such an issue is outside the Committee's charge, competence, and prerogatives. Decisions of that kind must be made by the Vietnamese within the context of their land-use policies.

D. Provisions Included in the Contract

In order for the Committee to maintain complete independence, and at the same time to protect cooperating individuals, the following provisions were included in a Modification to the Contract between NAS and DOD:

"a. Planning, direction and execution of this study to meet the requirements of the contract are the exclusive responsibility of the National Academy of Sciences through the Committee on the Effect of Herbicides in Vietnam including the selection and appointment of scientific and technical personnel needed to carry out the work.

"b. All Department of Defense material will be fully available to cleared members of the Committee and that portion of the classified information needed in their opinion for the study and the report will be given immediately to DDR&E who will initiate declassification action on a priority basis. It is the intent of both parties to adhere to the principles expressed in the correspondence between Dr. Handler, NAS, and Dr. Foster, DDR&E (Dr. Foster to Dr. Handler, 15 October 1970; Dr. Handler to Dr. Foster, 26 October 1970; Dr. Foster to Dr. Handler, 14 November 1970; Dr. Handler to Dr. Foster, 7 December 1970). It is further the intention of DOD to enable a full and comprehensive report at the earliest possible date. It is noted that data concerning amounts, types, dates and locations of herbicide releases in Vietnam were of prime interest to the Committee, and that all such information has been declassified and placed at their disposal.

"c. Fifteen (15) days following submission to the Congress, reports submitted under this contract may be made available to the public by the Academy and DOD through normal and accepted channels without restriction. The Academy may publish such reports 45 days after submission to DOD. The Academy may further authorize publications by committee members with credit to study, subject only to the restrictions outlined herein.

"d. Statements of individuals gathered in and for the performance of this contract are not to be disclosed to anyone without prior consent of the respondent.

"e. Data from surveys gathered in and for the performance of this contract shall not be attributed to any individual without his written permission.

"f. It is explicitly understood that studies in repair and rehabilitation of any damage detected will be included in the study.

"g. Every effort should be made to safeguard the privacy and welfare of all respondents in the study, regardless of their political positions or their responsibilities regarding defoliation.

"h. All publicity must be agreed upon in advance and coordinated between the Department of Defense and the Academy."

E. Cooperation

(1) Cooperation of U.S. and SVN Military Authorities

As explained before, the Committee worked under a contract between NAS and DOD. From the preceding section it should be evident that it had exclusive jurisdiction of planning, staffing and execution of its work. On the other hand, the Committee has been dependent on DOD for much of the documentary material necessary for its work, and on logistic support for much of the travel in SVN.

This was explicitly stated in the contract. Regarding documents, it was understood that classified information that the Committee considered essential for its report or as back-up material, would be declassified. How, then, has DOD discharged its obligations towards the Committee?

The Committee's immediate liaison in DOD, Mr. T. R. Dashiell, Deputy and later Staff Specialist, Chemical Technology, Office of Director of Defense Research and Engineering (DDR&E), DOD, has been exceedingly helpful to the Committee. Mr. A. E. Hayward, formerly Assistant Director (Environmental and Life Sciences), DDR&E, who retired in June 1972, was also very helpful. So far, all requests for declassification of documents have been honored. The declassified material was provided to the Committee and treated as privileged information, with the understanding that those materials that have been used in this report or are necessary as supporting information would become public when the report has been submitted to Congress as provided in the contract.

DDR&E has also absorbed the cost of air transportation of Committee personnel in SVN by MACV and Air America (see below), of the aerial photography flown for the Committee, of computer time for the preparation of some spray mission map overlays, and of shipping supplies and samples between Saigon and the U.S. The U.S. Army Engineer Topographic Laboratories in Washington has been most cooperative in obtaining existing aerial photography of SVN and assisting in its analysis. This was authorized through DDR&E.

In SVN, the directors of the Advanced Research Projects Agency (ARPA) Field Unit in Saigon were most helpful, providing office space, equipment, and various services, and helping out generously with ground transportation.

Of the American liaison officers attached to the Committee and charged with assisting it, Major Paul Gardner was outstanding, because of his highly responsible attitude to his assignment and because of his fluency in Vietnamese. The commanders of U.S. military bases and field units (Dong Xoai, Nam Can, Vung Tau) and likewise their counterparts in ARVN, who had to provide us with local transportation, housing, and/or security, were uniformly cooperative and helpful. Individual officers and offices at MACV Headquarters were very cooperative.

On some occasions, however, assistance or information were not provided as promptly as they ought to have been. Thus the so-called HES gazetteer tapes (a non-classified computerized listing of population size, location, and administrative jurisdictions) were requested in July 1972 from CORDS at Saigon, but while the request was approved, and despite repeated reminders, only parts of the material were delivered, and only over a considerable period of time. The complete tapes could be obtained only a year later from the Office of the Director of Defense Program Analysis and Evaluation, DOD (Pentagon). The Assistant Director of this Office and his associates were very helpful, but because of the delay which we suffered with this material we were unable to carry out a correlation of herbicide missions and population patterns, a task which the Committee considered of high priority. Other very frustrating delays occurred repeatedly in delivery of aerial photographs, even after they had been assembled and declassified.

Air transportation, provided at first directly by MACV and later through Air America, involved repeated frustrating periods of waiting, especially in the earlier period of our work, and it was sometimes not known almost until take-off time whether or not a flight would leave. Ultimately, however, all requested flights were arranged and made, except if security considerations necessitated a change. With ground transportation, matters were much worse. Only at the very end of its activities in SVN was the Committee able to obtain a vehicle directly from MACV. Before that, arrangements were made through JUSPAO and the American Embassy, but they were subject to cancellation practically without notice, and the vehicle provided was old, poorly maintained and unreliable. Requests to assign a helicopter and an adequate ground vehicle with absolute priority for Committee use remained without action. We learned to overcome these problems, but if we had had to rely for ground transportation exclusively on the good offices of the U.S. authorities in SVN our work would have suffered grievous delays, and many studies would have remained uncompleted.

Transportation on the water and some air transportation in the mangrove were provided by the RVN Navy and Air Force, and as our work progressed during the withdrawal of American armed forces from SVN we came to rely increasingly on direct contacts with the RVN armed forces. Their cooperation was most generous and very prompt; indeed our work in the mangrove (except our experiments in the mangrove near Vung Tau; see Section V A) would not have been possible without their assistance.

Special thanks should go to the successive Commanders of the Naval Base at Nha Be, south of Saigon, and their Chief of Staff; the Commander of the Naval Base at Vung Tau; the Commander of the Tran-

Hung-Dao strongpoint in the Rung Sat Special Zone where several Committee members and associates spent several nights; and the Commander of the Popular Forces Training Center near Vung Tau and the City Council of Vung Tau who authorized our studies in a mangrove area near Vung Tau which was within the perimeter of the Center.

(2) Cooperation with Vietnamese

The study centers on the effects of herbicides in SVN. Thus, it is almost axiomatic that the investigation should include Vietnamese, as it is the Vietnamese people who must live with the results of defoliation and other war-related activities and who, we hope, may derive some benefit from the results of our study. The Committee's work was approved by the office of the Prime Minister of the RVN. The cooperation of the RVN armed forces and some other RVN authorities has been acknowledged. Generous cooperation was also received from the RVN Ministry of Health and the staff of the Barsky Unit of Cho Ray Hospital. Many Vietnamese served as consultants, or helped the Committee in less formal but no less important ways, either in actual work or by providing information and materials. Without this cooperation it would have been possible to carry out only a very small part of our work.

II. BACKGROUND MATERIAL

A. Development of Herbicides and Their Uses in the Tropics[a]

The use of herbicides for vegetation control is not a new practice. The first recorded use of a chemical for selective killing of a weed was in 1896, when a French viticulturist observed that wild mustard was selectively killed by the newly discovered fungicide, Bordeaux mixture. He showed that this effect was due to the copper sulfate contained in the fungicide. An important development occurred following the discovery of the first plant hormone, auxin, by F. W. Went in 1926. Auxin was identified as indole-3-acetic acid, a chemical which had been known as a synthetic product for quite some time. Subsequent research showed that a considerable number of other chemical compounds had physiological activities similar to those of auxin. The first of these synthetic auxins were analogs of indole-acetic acid itself (indole-3-propionic acid, indole-3-butyric acid). Somewhat later, in the 1940's, it was, however, found that chemically less related compounds, mainly certain chlorinated phenoxyacetic acids, also possessed auxin activity and, moreover, that some of them, when used at relatively high doses, killed certain plants in a very effective manner but did not harm others. These compounds were thus selective herbicides. One of them, 2,4-D ([2,4-dichlorophenoxy]acetic acid) became, in fact, the most widely used commercial herbicide; another, 2,4,5-T ([2,4,5-trichlorophenoxy]acetic acid) was used particularly as a killer of brush and other woody plants which were comparatively resistant to 2,4-D. 2,4-D and 2,4,5-T were two of the herbicides widely used in the Vietnam war. A third compound, picloram, which was also used in this war, was discovered much later and is chemically unrelated to 2,4-D and 2,4,5-T but resembles them in possessing auxin activity and in its selectivity range. The fourth chemical used for military purposes in SVN, cacodylic acid, is a general plant killer not having the degree of phytotoxic selectivity exhibited by 2,4-D, 2,4,5-T, and picloram.

Use of herbicides in the tropics is also by no means new. They were seen as means of reducing labor costs and of bringing more land into cultivation by eradicating the native vegetation, and have helped to develop new practices of crop production that increased efficiency

---

[a] Here and in the rest of this report, discussion is limited to those herbicides that have been used for military purposes in SVN.

and yields (e.g., elimination of soil cultivation after planting of sugarcane, pineapples, and tree crops and the direct seeding of rice on uncultivated paddies). It should not be overlooked, however, that in tropical and other underdeveloped countries herbicides also may have negative effects of both a direct and indirect nature, such as inadvertent damage by spray drift onto adjacent vegetation the herbicide sensitivity of which may be insufficiently known, or reduction of the need for labor which may lead to unemployment with its attendant problems.

B. The Military Use of Herbicides in SVN

Research on 2,4-D, 2,4,5-T and related herbicides began during World War II, and had at that time a clearly military connotation. However, herbicides were not used for military purposes in World War II. The first, small-scale military use of herbicides was in the 1950's in the Malayan "emergency." In the early 1960's the possibility of tactical use of herbicides was given considerable impetus. A number of herbicides were evaluated, in various combinations, for their phytotoxic effectiveness in SVN. Evaluations were also made in Thailand near Pran Buri, in Hawaii, and in Puerto Rico. The Committee was able to use some of the test sites at Pran Buri for its studies, mainly on persistence of herbicides and their possible effects on soil, and to observe the present condition of vegetation in the test sites in Puerto Rico.

(1) The Course of the Military Herbicide Operations in SVN

In SVN, the first military herbicide operations were carried out in early 1962, and were phased out in 1971. After a relatively slow buildup from 1962 to 1965, the operations increased rapidly to a peak in 1967, declined, but only slightly, in 1968 and 1969, and dropped sharply in 1970. According to information from DOD, the last herbicide spraying by fixed-wing aircraft was flown on January 7, 1971. After this, herbicide operations were limited to spraying around perimeters of the fire bases, on enemy cache sites, and along land and water communication routes, and were all carried out by helicopter or on the ground. The last helicopter operation under U. S. control was flown on October 31, 1971.

Details of the herbicide operations for the period August 1965 through February 1971 will be given in Sections III A and B; information not covered in these sections will be discussed in Section III C.

(2) The Herbicidal "Agents" Used

The herbicidal "Agents" used for military purposes in SVN were identified by code names referring to the color of bands painted on the containers of the chemicals: Orange, White, Blue, and Purple.

Agent Orange is a 50:50 mixture of the n-butyl esters of 2,4-D ([2,4-dichlorophenoxy]acetic acid) and 2,4,5-T ([2,4,5-trichlorophenoxy] acetic acid). Each gallon of Orange contains 4 lb of 2,4-D and 4.6 lb of 2,5,5-T on an acid equivalent basis.[a] Orange was the agent used

[a] Acid equivalent is the weight of the acid form of the chemical. This is used because the weights of various ester or amine formulations vary. Expression in terms of acid equivalents provides a uniform basis for comparison of different formulations.

most extensively in the Vietnam war until its use was terminated on April 15, 1970 because of concerns of its possible teratogenicity and its contamination with the highly toxic TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin; see Section II C-6).

Agent Purple is a 50:30:20 mixture of the *n*-butyl ester of 2,4-D, and the *n*-butyl and isobutyl esters of 2,4,5-T. It was used only until 1964 and was then replaced by Agent Orange.

Agent White is a mixture containing 2 lb of 2,4-D and 0.54 lb of picloram (4-amino-3,5,6-trichloropicolinic acid) per gallon on an acid equivalent basis. It is a formulated product containing 2,4-D and picloram as the triisopropanolamine salts, with the addition of surfactants and water.

Agent Blue is formulated as the sodium salt of cacodylic acid (hydroxydimethylarsine oxide). It contains a minimum of 21 percent sodium cacodylate with additional free cacodylic acid for a total dimethylarsinic acid equivalent of not less than 26 percent on a weight basis, or 3.1 lb of cacodylic acid and about 1.7 lb arsenic per gallon, with 5 percent surfactant and 0.5 percent antifoam agent.

All agents were intended for use at a rate of 3 gal./acre (28 liters per hectare), except that in the earlier operations and on rare occasions thereafter, only half of this dose was used. The herbicides were applied by fixed-wing aircraft (UC-123), helicopter (UH-1), from trucks, from river boats, and from backpacks (see Figs. II B-1 to B-4). Both aircraft types were outfitted with special spraying equipment, consisting essentially of a container for the herbicide and a spray boom with nozzles. The container of the UC-123 spray system had a capacity of 1000 gal. and the plane normally flew at 150 ft. (45 m) with a delivery speed of 130 to 140 knots. The "spray-on" time of 3 1/2 to 4 minutes permitted approximately 950 gallons of herbicide to be distributed at the rate of 3 gal./acre. The capacity of the UH-1 spray system container was 200 gal. but the helicopter could carry only 100 gal. because of weight limitations. Trucks used for herbicide spraying were tanker trucks with a 50 or 100 gal. capacity. Spraying by river boats was done directly from the original 55 gal. drums of the agents; backpack sprayers had 3 gal. drums. Spraying by fixed-wing aircraft accounted for the great majority of the herbicide used in the Vietnam war, at least into the later part of 1970 from which time on helicopter herbicide operations increased and gradually became predominant, until they became the only aerial means of herbicide delivery.

(3) Military Classification of the Herbicide Operations in SVN

Two main objectives of herbicide operation were distinguished by the military authorities: (1) defoliation, defined as "the use

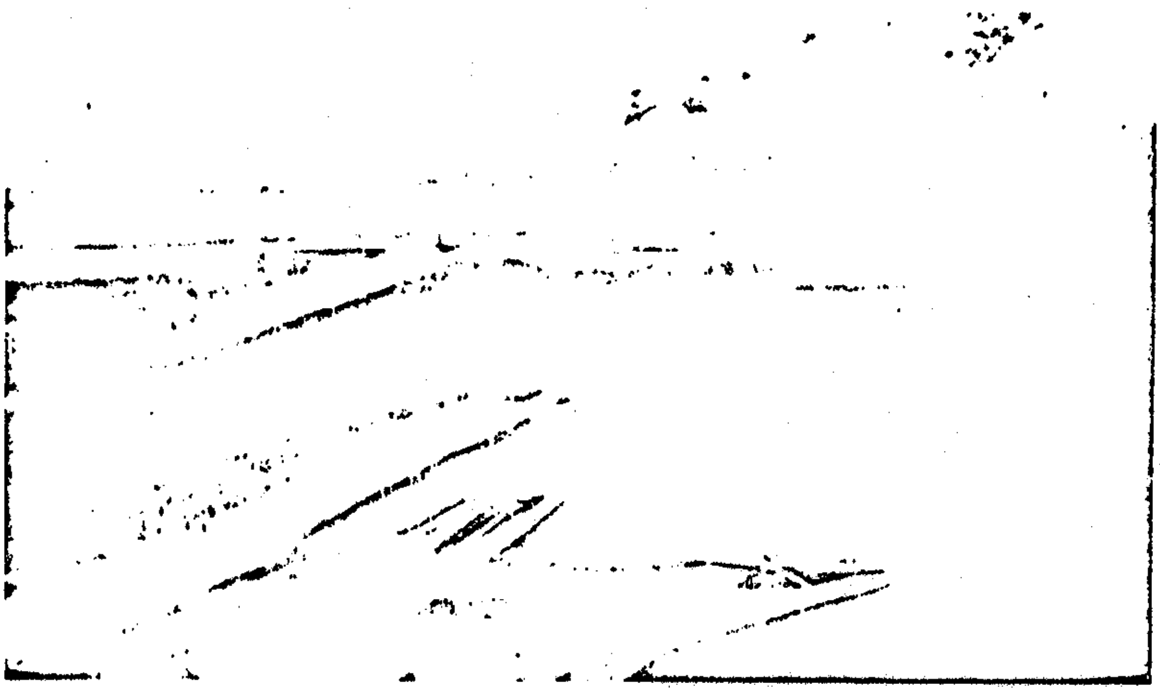


Fig. II B-1. Four fixed-wing UC-123 aircraft on a spray mission in Phuoc Long Province. Photo taken in 1969 by Colonel Harold C. Kinne, Jr.

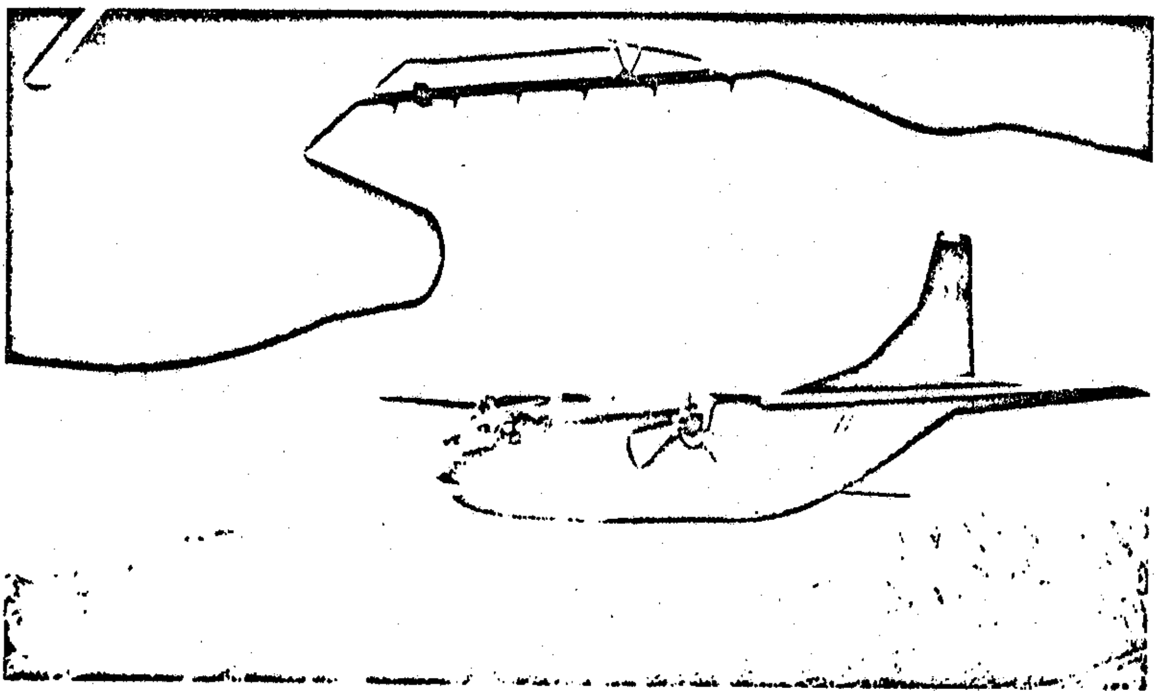


Fig. II B-2. UC-123 aircraft showing wing and tail spray booms. Photo taken in 1969 by Colonel Harold C. Kinne, Jr.

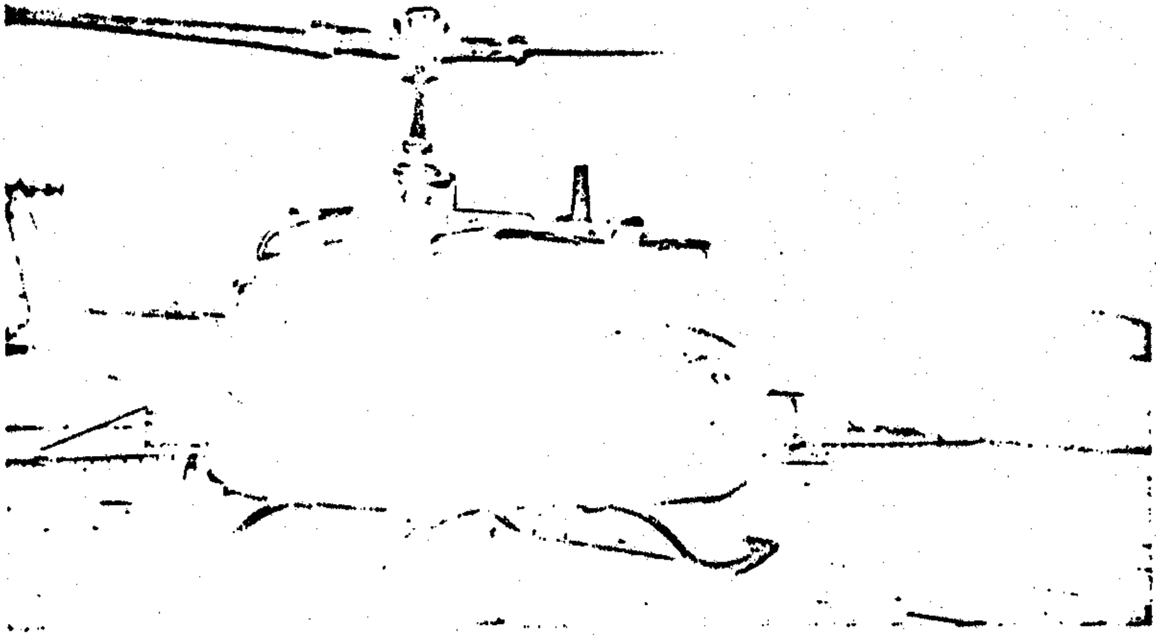


Fig. II B-3. UH-1D helicopter equipped to dispense herbicides. DOD (U.S. Army) photo taken in 1968.

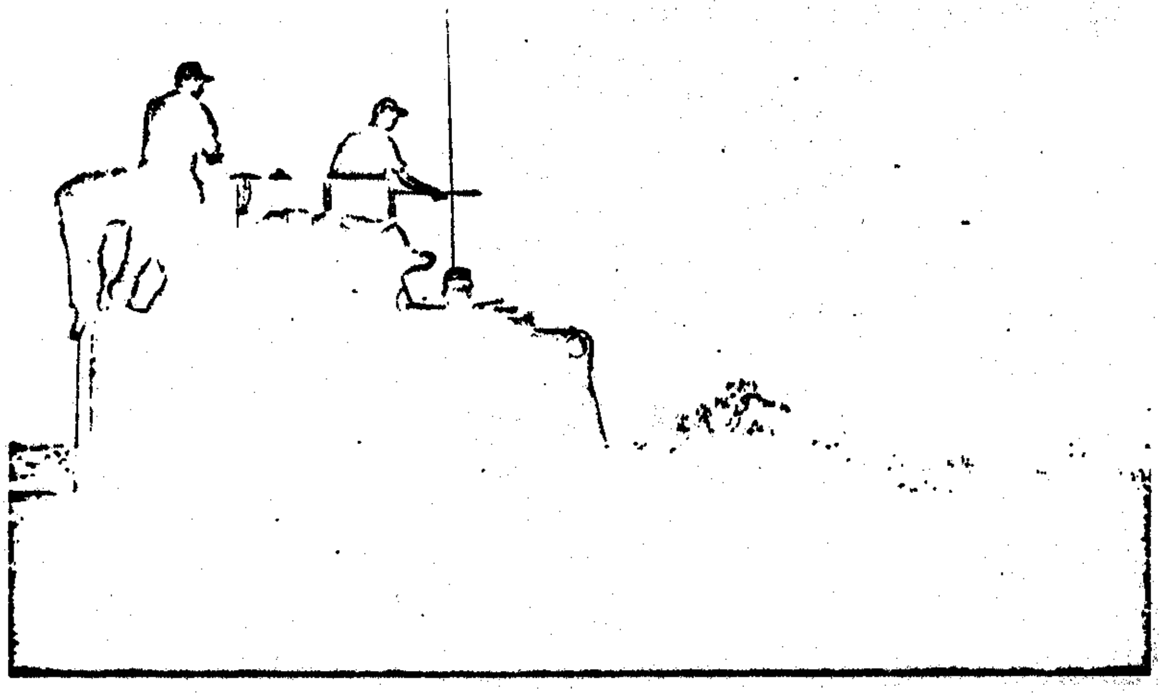


Fig. II B-4. Ground spraying of herbicides in Di-An. DOD (U.S. Army) photo taken in May 1968.

of herbicides to cause trees and plants to lose their leaves in order to improve observation," and (2) crop destruction, defined as "the application of herbicides to plants to destroy their food value" and directed at crops of hostile forces (definitions from MACV Directive No. 525-1, August 12, 1969). Herbicides were also used, although on a much smaller scale and only by helicopter or on the surface (ground or water), for clearing vegetation around the perimeter of fire support bases and other military installations, on landing zones and enemy cache sites, and along lines of communication. The objective of these latter uses was, however, also defoliation or destruction of vegetation for better visibility. Thus, there were essentially two military objectives of all herbicide operations, defoliation and crop destruction. While this distinction has been followed to some extent in the inventory of herbicide operations (Section III) as will be explained later (Section III B), it has very little meaning as regards their physiological and ecological effects.

(4) Authorization and Tactics of Herbicide Operations

Approval and conduct of herbicide operations in SVN were subject to directives, the intent of which was to ensure maximum deposition of the agent on the selected target, and to minimize damage to "friendly" crops and other adverse effects.

Herbicide operations could be approved in two ways. In the more common case, one or several "target areas" in a province were approved for herbicide treatment for defoliation or crop destruction, and individual herbicide spray flights, called missions or sorties,[a] were then carried out by "Ranch Hand," the U.S. Air Force unit charged with herbicide operations, on a priority basis. All missions within a target formed a project. A defoliation project was authorized for six months, a crop destruction project for one year; both could be extended for six more months. In other cases--apparently, in those considered particularly urgent--authorization could be sought for individual missions or sorties.

The authorization process was the same in either case, and with certain exceptions noted below required concurrence of both RVN and U.S. authorities at Province (or Division) and the Military Region[b] level, by the RVNAF Joint General Staff, COMUS,[c] MACV and the American Ambassador. This was regardless of whether a request originated on the RVN or the U.S. side.

---

[a] A mission consisted mostly of several aircraft each of which formed a sortie; if only one craft was used the operation was termed a sortie.

[b] SVN was divided into four Military Regions, each corresponding to a Corps (see Section E).

[c] RVNAF = Republic of Vietnam Armed Forces; COMUS = Commander, U.S.

On the RVN side, the authorization process started with the Province Chief and was transmitted to the ARVN Commander of the MR and thence to a special committee of the RVNAF Joint General Staff ("202 Committee"); it was also transmitted to the U.S. Division Commander in whose command the province was included, and on to the Senior Advisor of the MR and to the U.S. Mission "203 Committee." The Province Chief had to provide an analysis of the target area(s), including intelligence, psychological warfare and civic affairs evaluations (e.g., number of people in and near the target areas, their ethnic characteristics, and their political attitude; anticipated psychological effects including NLF propaganda and measures to counter same; creation of refugees). He also had to give a written pledge of indemnification for damage to "friendly" crops. On the U.S. side, the Senior Advisor was charged with considering the same and some additional problem areas (effects on pacification operations, community development, economics) and had to obtain the opinion of the representative of CORDS, the Agricultural Advisor, and others, although adverse opinion from the latter quarters could be overruled. The "203 Committee" was expected to consider the proposal from the viewpoints of planning, intelligence, CORDS, USAID, JUSPAO, and the American Embassy. Usually, an aerial reconnaissance of the target area(s) was made. If the proposal had been approved by all above authorities it was submitted for the approval of the Commander of MACV and the American Ambassador. The entire procedure is shown diagrammatically in Fig. II B-5. Disapproval by either party at any level was binding. Forty-eight hours prior to each mission, final approval had to be obtained from the Province Chief and all ground commanders having a responsibility in the target area.

The above procedures were mandatory for all crop destruction operations and for defoliation operations by fixed-wing aircraft. Authorization for defoliation missions by helicopter and on the ground were delegated to the RVN and U.S. authorities at the MR level (see Fig. II B-5). After each mission, a report had to be prepared and submitted to MACV. These reports were to include project and target number, date of mission, number of sorties scheduled and number productive (number of aircraft), reasons why scheduled sorties were not productive (when applicable), type and number of gallons of agent and type of mission (crop destruction or defoliation), hits sustained by spray aircraft and UTM coordinates of actual spray run. In addition, there were regular periodical evaluations of each herbicide project.

In order to verify that the policies and procedures governing herbicide operations were adhered to, the original project and mission files were reviewed by a special task force from MACV and the American Embassy, and as a result a Report on the Herbicide Policy Review was issued in 1968. The conclusion was that, in general, policies and procedures were followed, but serious damage to "friendly" crops was noted. Several steps were recommended in order to improve the management of the herbicide operations. The main ones were (1) to insure full

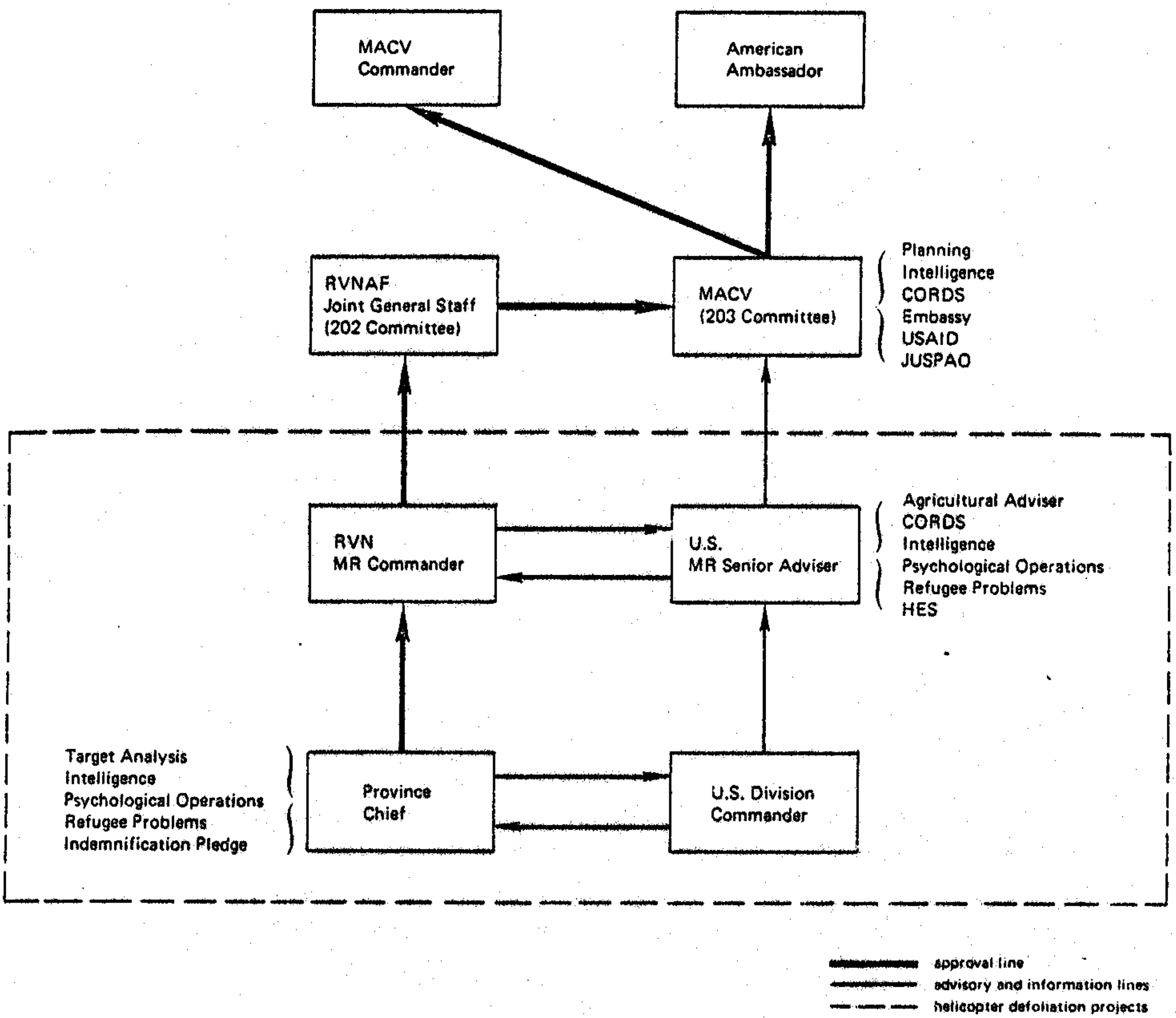


Fig. II B-5. Diagram of the routing of proposals for herbicide projects.

consultation of CORDS, agricultural, psychological operations, and refugee specialists; (2) to require complete checklists for all relevant military, demographic, economic, and psychological information and their evaluation by Saigon-level officials; (3) to require regular post-operation audits; (4) to limit, in accordance with a wish of the Government of RVN, herbicide operation to "low population density areas," defined as areas with no more than seven persons per square kilometer.[a] MACV took these recommendations into account in a revision of the procedures for authorization and execution of herbicide operations in August 1969 (MACV Directive 525-1). In 1970, another Herbicide Policy Review was conducted by the "203 Committee" (report issued in November 1970). It concluded that the serious damage caused by herbicides to crops under friendly control in the past years had been almost eliminated by the recent restrictions (i.e. those recommended in the 1968 Report) placed on herbicide missions; that the current mission approval system afforded an adequate amount of control to personnel engaged in economic development; and that the current herbicide operations had little or no impact on the agricultural and economic development programs. At the same time, however, the report contained many highly critical opinions on the effects of the herbicide operations on crops, especially the actual crop destruction program, and on friendly populations.

REFERENCES

"Report." Herbicide Policy Review Committee, American Embassy, Saigon and MACV. Classified version, May 1968; unclassified version, August 1968.

Hq., U.S. Military Assistance Command, Vietnam (MACV), Directive 525-1, dated 12 August 1969, with four Annexes.

"203 Committee" "Report on the Herbicide Policy Review (U)" 1970 Hq., U.S. MACV, Saigon, (Interagency 203 Committee) November 18, 1970. Classified.

---

[a] Although, in general, missions were conducted in such areas, the Committee encountered examples of missions flown directly over or in the immediate vicinity of inhabited settlements (Section VII B-1).

C. Biological, Physical, and Chemical Characteristics of the Herbicides Used in the Vietnam War

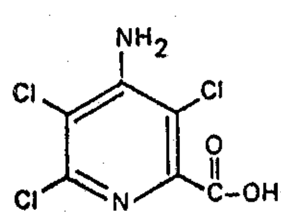
In order to understand the effects the herbicides used for military purposes in SVN may have had it is necessary to be familiar with what is known of their physical, chemical, and biological properties, including their toxicity. The reader should understand that the herbicides used for defoliation and crop destruction in SVN are also used for civilian purposes, some on a very wide scale, although the use of some of them is, or has recently been restricted in the U.S. and some other countries. In Table II C-1, a key is given to convert the dosages in which herbicide applications are usually expressed (lb/acre), into concentrations caused in soil or water. The dosages used on crops range from one-tenth and below to one-fifth, and those on pastures, rangeland, some aquatic sites, and for certain uses in forestry between one-tenth and one-half, of those used in the military herbicide missions in SVN.

Specific information on the characteristics of the agents used in the herbicide operations in SVN is scarce; therefore, the data given relate mostly to the individual components. We shall begin with picloram, present in Agent White, and cacodylic acid, the herbicidal component (as acid and salt) of Agent Blue as relatively little is known on many properties of these compounds and as they were not causes of the greatest public concern. Then, we shall summarize pertinent data on 2,4-D and 2,4,5-T as well as TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin), a contaminant of 2,4,5-T. 2,4,5-T and 2,4-D are the most widely used compounds in herbicide operations in SVN (both of them as the components of Agent Orange and its precursor, Agent Purple; 2,4-D also as a component of Agent White). Because fetal toxicity and teratogenicity are questions of considerable public concern, they are reviewed as a separate item.

(1) Picloram

(a) Physical and chemical properties; Fate and effects in plants and soil.

Picloram is manufactured by chlorinating alpha-picoline, hydrolyzing the product, and reacting with ammonia.



Picloram

Table II C-1

Relation between Herbicide Dosage, and Initial Concentration in Soil and Water

	Dosage lb/acre	Concentration, ppm 3 in. depth	1 ft depth	3 ft depth
Soil	1.0	1.00	0.25	0.08
	1.6	1.60	0.40	0.13
	6.0	6.00	1.50	0.48
	9.3	9.30	2.33	0.78
	12.0	12.00	3.00	0.96
	13.8	13.80	3.45	1.15
	25.0	25.00	6.25	2.08
Water	1.0	1.48	0.37	0.12
	1.6	2.37	0.59	0.19
	6.0	8.88	2.22	0.73
	9.3	13.76	3.44	1.15
	12.0	17.76	4.44	1.38
	13.8	20.42	5.11	1.70
	25.0	37.00	9.25	3.08

The concentrations are calculated assuming that all herbicide is limited to the depth indicated, and is evenly distributed within this depth. The concentrations in soil are average values for a soil bulk density of 1.43. The actual concentrations will depend on soil type and may vary as much as 10 percent from the figures given. Dosages used in a single herbicide mission in SVN were:

<u>Agent Orange</u>	
2,4-D	12.0 lb/acre
2,4,5-T	13.8 lb/acre
<u>Agent White</u>	
2,4-D	6.00 lb/acre
Picloram	1.62 lb/acre
<u>Agent Blue</u>	
Cacodylic Acid	9.3 lb/acre

Picloram is slightly soluble in water (430 ppm at 25°C [77°F]) but the salts are highly soluble (potassium salt: 40 percent at 25°C [77°F]). The acid and salts have an extremely low volatility (vapor pressure of the acid: 6.16 x 10^{-7} mm mercury at 35°C [95°F]) and are stable below 215°C (419°F).[a]

Picloram is readily absorbed by and translocated throughout the plant. In a wide range of species, it can persist as the intact molecule in the tissues for a long time but exceptions have been noted where rapid metabolic conversion has taken place. Deformity of young leaves and loss of chlorophyll can be observed soon after treatment, but it may take several months to kill trees. The selectivity of picloram is comparable to that of the phenoxy herbicides (Section II C-3). Broadleaf plants are generally considerably more susceptible than grasses; tomatoes, cucurbits and many legumes are particularly sensitive.

The behavior of picloram in plants is also similar to that of 2,4-D and 2,4,5-T: the concentration declines rapidly soon after treatment, but at a slower rate in later stages. In live oak treated with 2 lb/acre, the residues after 1 and 6 months were 7 and 0.02 ppm; in sugarcane treated with 2 to 3 1/2 lb/acre, they were between <0.1 and 0.6 after 42 days.

In soil, picloram is generally much more stable than 2,4-D and 2,4,5-T. Detectable residues have been sometimes found up to two to three years after application at agricultural rates. Under some conditions, including low pH, high organic matter content and others which cannot yet be specified, degradation can, however, be relatively rapid.

Limited work on the effects of picloram on soil microorganisms has shown that many species tolerate concentrations as high as 1000 ppm (Goring et al., 1967). Mineralization of nitrogen and respiration was not affected at 500 ppm. However, in experiments by Dubey (1969) on tropical soils significant inhibition of nitrification occurred at 20 ppm. In SVN, a single application of Agent White resulted in a picloram concentration of around 1 ppm or less according to soil type and water content and the distribution in the soil profile (see Table II C-1).

Because of its very low volatility, picloram is highly unlikely to cause damage by lateral movement of vapor in the air. On the other hand,

---

[a] Compounds with a vapor pressure of less than 10^{-7} mm mercury may be considered as non-volatile; those with a vapor pressure of 10^{-6} to 10^{-5} mm mercury as moderately; and those with one of 10^{-5} mm mercury or more as highly volatile.

its high solubility and consequent liability to leaching may result in problems of herbicide movement in both surface and drainage waters. There are several reports in the literature of highly sensitive crops exhibiting signs of picloram injury following the application of compost made from the residues of crops receiving picloram or even from manure made with the dung of animals grazing treated fields.

(b) Effects and fate in animals, including man.

The following information relates in part to picloram and in part to the combination of picloram and 2,4-D (Agent White).

The acute oral toxicity of picloram and its salt and ester formulations for mammals, as determined by single dose studies, is low. The LD_{50} values[a] range from about 2000 mg/kg of body weight for rabbits to more than 8000 mg/kg for rats (Ebbersten, 1972; McCollister and Leng, 1969). Single doses up to 720 mg/kg were administered to sheep, and up to 540 mg/kg to calves with no evidence of toxicity (McCollister and Leng, 1969).

Studies on chronic toxicity of picloram have been reported by McCollister and Leng (1969). Their principal results are as follows: (a) When picloram was fed to rats for 90 days it caused no adverse effects with daily dietary levels as high as 1000 ppm, and at 3000 ppm, only an increase in the liver/body weight ratio of female animals. At 10,000 ppm in the diet, slight to moderate pathological changes were observed in the liver and kidneys. (b) The triisopropanolamine salt of picloram, fed to rats for 90 days at a level of 3000 ppm, has a toxicity comparable to the acid. (c) Albino rats and beagle dogs fed picloram in their rations showed after two years of continuous feeding, at daily levels of 15, 50, and 150 mg/kg of body weight, no observable adverse effect as measured by body weight, food consumption, behavior, mortality, hematological and clinical blood chemistry studies, and urinalyses. No gross or microscopic changes were seen, and no difference could be detected in the incidence or kind of tumors found in control rats and in animals receiving picloram in their diet. Similar results were obtained for sheep, calves, and swine. (d) No evidence of adverse effects on fertility, gestation, viability, lactation, body weight, or fetal morphology were noted in albino rats fed picloram at various levels up to 3000 ppm in their diet through three generations. In tests with mice treated with 1000 ppm of picloram in their diet for 4 days before mating and 14 days after mating, there was no effect on number of offspring produced.

Tissue distribution and retention studies with cattle, sheep, chickens, and dogs showed that picloram behaved much like 2,4-D and

---

[a] Mean lethal dose--the amount of a toxic agent which when applied as a single dose will be lethal to 50 percent of the test animals to which it is administered, usually expressed in milligrams per kilogram body weight (mg/kg).

2,4,5-T (McCollister and Leng, 1969; Kutschinski and Riley, 1969; Getzendaner, 1973). In lactating cows, dietary levels of at least 300 ppm were necessary to produce detectable residues in the milk; in steers, diet concentrations of 200 to 1600 ppm resulted in residues of 0.05 to 0.3 ppm in muscle and fat and up to 18 ppm in the kidneys; three days after withdrawal, the residues in cow milk had disappeared (<0.05 ppm) and those in the edible tissues of steers including the kidneys had dropped to 0.1 ppm or less.

Feeding studies with birds, fish and other aquatic animals were conducted by McCollister and Leng (1969); other studies with fish have been summarized by Kenaga (1969). Tests on several species of wild birds failed to reach the LC50 at 1000 ppm in the diet.[a] Japanese quail were fed 100 to 1000 ppm of picloram in their diet for each of three generations without effect on mortality, body weight gain, egg production, fertility or hatchability. LC_{50} values (concentration in water) for several species of fish including trout, salmon, minnow, bluegill, catfish species, and goldfish ranged generally between 20 and 100 ppm for a 24 hr exposure and, as might be expected, somewhat less for longer exposure times. There was not much difference between the free acid and various salts. Combinations with 2,4-D (including Agent White) or 2,4,5-T were more toxic, particularly those with some esters. Various formulations containing triisopropanolamine salts of 2,4-D and picloram were more toxic to ramshorn snails than those without 2,4-D, but none were shown to be toxic at concentrations below 100 ppm in water. Studies with *Daphnia* showed no effect on reproduction and no evident toxicity below 127 ppm. Analysis of *Daphnia* tissues showed no concentration above that occurring in the water.

No studies or reports on toxicity of picloram in man are available. If one may extrapolate from animal work, the toxicity rating of picloram for man on the scale of Table II C-6 would be 3 and the toxic dose higher than that of 2,4-D and 2,4,5-T.

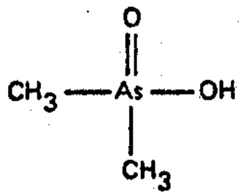
(2) Cacodylic Acid

(a) Physical and chemical properties; effects and fate in plants and soil.

Cacodylic acid is manufactured by reducing disodium methane arsonate with sulphur dioxide, and methylating the sodium salt to the resultant arsenomethane. The solubility in water of both the acid and sodium salt is extremely high (over 10 lb/gal.). The chemical is non-volatile and stable in sunlight.

---

[a] Mean lethal concentration--the concentration of a toxic agent in a medium (diet, water) that causes death of 50 percent of the animals.



Cacodylic Acid

Cacodylic acid is primarily classified as a contact herbicide because it lacks mobility and only kills tissues into which the chemical has penetrated from the spray drops. At normal rates phytotoxic symptoms appear within two days. It is less effective if rain falls within a few hours of treatment. Sub-lethal doses induce defoliation, malformed inflorescences and fewer seeds. Cacodylic acid appears to undergo little breakdown in plant tissues.

In the soil cacodylic acid undergoes degradation by the microflora. Breakdown is slow under aerobic conditions but is more rapid in flooded, anaerobic soils. The ultimate environmental fate is a change to inorganic arsenate which is mostly bound as insoluble compounds in the soil. Soils naturally contain arsenic in this form, the average content being 5 ppm (Schroeder and Balassa, 1966). In Southeast Asia, sodium arsenite has been applied in rubber plantations at high rates for over 20 years without apparently causing any crop injury.

Although plants absorb cacodylic acid from the soil more readily than inorganic arsenic the available evidence suggests that crops ordinarily do not suffer injury when planted on land which has been previously treated. If excessive rates have been used and/or the soils are unusually rich in phosphates, injury may be caused to sensitive plants (such as rice and peanuts) when planting takes place soon after treatment (Woolson, personal communication).

(b) Effects and Fate in Animals, Including Man.[a]

The toxicity rating of cacodylic acid for humans on the scale of Table II C-6 is 3, that is, the substance is in the lower range of materials with a medium toxicity. Toxicologic data for animals are available

---

[a] Except where a reference is given, the information in this section was obtained from the supporting material included in petition for registration of the compounds as herbicides.

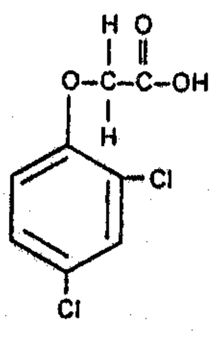
for Ansar 160 and Ansar 560, both of which are reasonably similar to Agent Blue.[a]

Ansar 160 has an approximate LD_{50} of 3.2 cc/kg for albino rats, Sprague-Dawley strain; for Ansar 560 the LD_{50} was 2.6 g/kg. Necropsy of animals that died after being fed the chemicals did not indicate any significant gross pathologic alterations in the examined tissues and organs. For a variety of non-mammals the LC_{50} ranged from values of several hundred to 1000 ppm for acute doses of cacodylic acid.

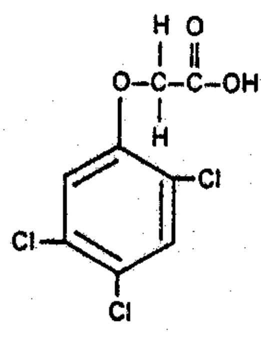
In studies on chronic toxicity, cacodylic acid was fed to rats at arsenic levels of 0, 3, 15, 30, and 100 ppm and to beagles at 0, 3, 15, and 30 ppm. There were no significant differences between control animals and test groups in terms of body weight, food consumption, hematology, urinalysis, or organ weights.

Lactating Holstein cows were given a supplemental feed of cottonseed meal containing 10 ppm of cacodylic acid equivalent to a daily intake of 24.5 mg. After 60 days on this regime, no arsenic residue in milk or cumulative storage in body tissues were found. Eggs from chickens fed arsenic levels of 0, 0.3, and 3.0 ppm contained less than 0.05 ppm arsenic, those from hens fed at the 30.0 ppm level had residues of 0.22 and 0.23 at one and two months, respectively. Tissue analyses showed arsenic residues in hens fed at 30 ppm, but after seven days withdrawal the tissue residue levels were again below 0.05 ppm, except for muscle which ranged from 0.06 to 0.10 ppm arsenic.

(3) 2,4-D and 2,4,5-T



2,4-D



2,4,5-T

(a) Physical and chemical properties.

The main steps in the manufacture of 2,4-D and 2,4,5-T are shown in Fig. II C-1. 2,4-D is produced by reacting 2,4-dichlorophenol with

[a] Ansar 160 contains 29 percent of sodium cacodylate and 5 percent of cacodylic acid, giving a total content in elemental arsenic of 16.28 percent. For Ansar 560, the values are 22.6 - 3.9 - 12.7 percent, for Agent Blue, 26.4 - 4.7 - 15 percent.

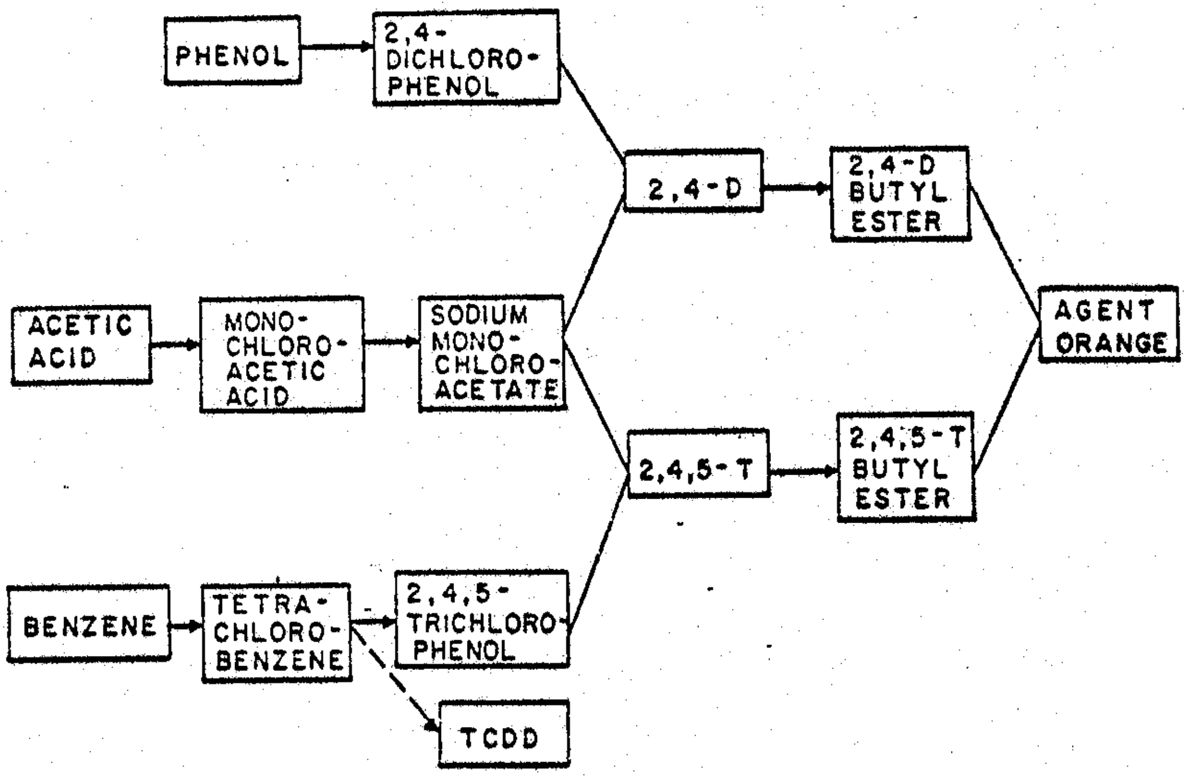


Fig. II C-1. Diagrammatic representation of the major steps in the production of 2,4-D, 2,4,5-T and Agent Orange. Also shown is the step where TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin) arises. No comparable material is formed in the 2,4-D process, because of the different conditions for the production of the dichloro- and the trichlorophenol (see Section II C[4]).

sodium monochloroacetate, while tetrachlorobenzene is the starting material for 2,4,5-T. The technical grades of 2,4-D and 2,4,5-T used for agricultural purposes are about 98 and 90 percent pure, respectively. Impurities consist mainly of chlorinated phenols and other chlorinated phenoxyacetic acids. 2,4,5-T also contains small amounts of TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin), a highly toxic compound the presence of which has caused considerable public concern. It is discussed in the next section (II C-4).

2,4-D and 2,4,5-T as the n-butyl esters are the constituents of Agent Orange. This agent is a liquid, very insoluble in water, but moderately volatile. The vapor pressure of the 2,4-D butyl ester has been determined to be 8.4×10^{-6} mm mercury at 25°C (77°F) (Hamaker and Kerlinger, 1969). No accurate determinations are available for the corresponding 2,4,5-T ester but estimates indicate that its volatility is of a similar magnitude to that of the 2,4-D ester. 2,4-D as the triisopropanolamine salt is a constituent of Agent White. In this form it is very soluble in water, and is essentially non-volatile. 2,4-D and 2,4,5-T in the forms used for herbicide operations in SVN are stable to well above ambient temperatures.

(b) Effects and Fate in Plants.

2,4-D and 2,4,5-T can be taken up by the root system and distributed throughout the shoots. When sprayed onto the foliage, penetration may occur and the chemicals are then freely exported from the leaves along with the products of photosynthesis, accumulating particularly in the most actively growing tissues where the disruptive effects on growth and the attendant metabolic processes are maximal.

Both 2,4-D and 2,4,5-T are distinguished by selectivity, that is, they affect certain plants much more than others. Broadleaved plants are as a rule susceptible, cereals and other grasses are relatively resistant. Although there is a voluminous literature on the action of 2,4-D and 2,4,5-T in the plant cell, it is not possible to pinpoint at the cellular level all the essential differences which determine susceptibility or resistance.

Within the plant, 2,4-D and 2,4,5-T are not very persistent. Table II C-2 lists the residues found in various crops after treatment with different doses and at different times after treatment. The disappearance is very rapid at first but slows down with time. It is caused by two concurrent processes: binding of the herbicide molecule to other compounds, mainly glucose, to form a non-toxic complex, and degradation of the herbicide molecule. The latter proceeds by removal of the side chain and replacement of the chlorine atoms with hydroxyl (OH) groups, followed by opening of the benzene ring. Formation of the corresponding phenols is a minor route of breakdown. The ability to degrade 2,4-D and 2,4,5-T varies between plant species.

Table II C-2

2,4-D and 2,4,5-T Residues in Crops

Crop	Treatment (lb/acre)	Interval between treatment and determination	Residue found (ppm)	Authority
		2,4-D		
Asparagus	2	1-3 days	2.0	Getzendaner, 1958
Peanuts	4			Getzendaner, 1965
Forage		62 days	0.1	
Nuts		150 days	ND[a]	
Sorghum	2.5	1-2 months		Ketchersid *et al.*, 1970
Forage			3-5	
Grain			<0.2	
		2,4,5-T		
Live oak	2	1-6 months	10-0.8	Bauer *et al.*, 1969
Rice	1.5	50 days		Devine, 1970; Jensen and Berhenke, 1973
Straw			0-13	
Grain			ND	
Wheat	1			Chow *et al.*, 1971
Plant		7-56 days	9-0.1	
Grain		56 days	ND	

[a] ND = not detected.

Because esters of 2,4-D and 2,4,5-T are much more volatile than acid and amine formulations, damage to susceptible plants can occur under some conditions by the lateral movement of the vapors. Plant injury may also be caused by drift of spray droplets from the treated area during spraying.

(c) Fate in Soil.

In the soil in the presence of moisture, even at relatively low levels, the esters of 2,4-D and 2,4,5-T are readily converted (hydrolyzed) into the acid form. Working with Canadian prairie soils at their wilting point moistures--that is, relatively low moisture content--Smith (1972) found that at 25°C (77°F) the n-butyl and the isopropyl esters of 2,4-D had decreased in one and one-half hours to 15 percent of the original level and had completely disappeared in 48 hours; hydrolysis of the isooctyl ester was slower, 20 to 30 percent remaining after 24 hr. and 10 percent after 48 hr. The free acids are more soluble than the esters but have still a low solubility (2,4-D, 620 ppm at 25°C [77°F] 2,4,5-T according to different determinations 251 or 278 ppm). Thus, as long as the two herbicides persist in the ester or acid form leaching through the soil will be slow. However, if sufficient amounts of certain metal ions (potassium, sodium, magnesium) are present and the soil is on the alkaline side salts of the acids are formed and these are highly soluble and thus subject to leaching.

Persistence of both 2,4-D and 2,4,5-T in the soil is limited. Disappearance follows a similar course as in plant tissue. It is caused by microorganisms and is therefore favored by environmental conditions which are favorable for high microbial activity: high organic matter content, moisture, and temperature. The breakdown can be enhanced in soils exposed previously to the same compound, or in some cases to related compounds. For example, it has been shown in Hawaii (Akamine, 1951) that after a single application 2,4-D takes up to 14 weeks to disappear, but after repeated applications decomposition occurs in four weeks or less. 2,4,5-T is somewhat more persistent than 2,4-D, but not greatly so.

(d) Effects on Soil Microorganisms.

Much research has been undertaken on effects of 2,4-D and to a lesser extent 2,4,5-T on soil microorganisms, which are essential in maintaining the properties of the soil, including properties important for agriculture. Significant effects from either herbicide have seldom been reported in laboratory experiments at concentrations of less than 100 ppm in soil. Both stimulatory and inhibitory effects have occurred at higher concentrations. No information is available for mangrove soils. Literature reviews (Fletcher, 1966; Audus, 1970) have concluded that these herbicides have no adverse effects at rates used in agricultural practice. In Vietnam, a single application of Agent Orange would have resulted in a mean concentration of 14 ppm 2,4,5-T and 12 ppm 2,4-D in the soil, assuming that all the chemical applied did reach the soil and was then restricted to the top 3 in. (7.5 cm), or about 3.5 and 3.0 ppm respectively, if it were restricted to the top one foot (30 cm) (compare Table II C-1).

(e) Effects and Fate in Animals.

Acute and chronic data on toxicology are available for the n-butyl and isobutyl esters, separately and in mixture, of 2,4-D and of 2,4,5-T, individually, but no data have been found for Agent Orange, which is the 50:50 mixture of the n-butyl esters. However, there is no evidence, one way or the other, that the n-butyl ester of 2,4-D would potentiate[a] the toxicological activity of the same ester of 2,4,5-T, or vice versa; the toxic effects of 2,4-D and 2,4,5-T formulations fall generally within the same dosage range, and formulated products containing various other esters of both 2,4-D and 2,4,5-T cause toxic effects in the same range as do the individual n-butyl esters of the two basic chemicals. Thus, we have made the assumption that the toxicological effects of Agent Orange are similar to those of its two components.

Rowe and Hymas (1954) reviewed earlier toxicological information on 2,4-D and 2,4,5-T and reported the results of extensive studies of their own. The LD_{50} values of various forms of 2,4-D and 2,4,5-T for rats, mice, guinea pigs, and rabbits range from 300 to 1000 mg/kg. Chicks appear to be somewhat more tolerant, and dogs more susceptible (LD_{50} 100 mg/kg).[b] Formulated products had LD_{50} values somewhat higher (500 to 2000 mg/kg), indicating that the adjuvants (surfactants, inert materials) did not appear to increase the toxicity of the basic chemicals. The LD_{50} values for the mixed butyl esters in mg/kg were as follows, with the 5 percent confidence limits or if noted with an * the range in which mortality was observed (administration here and below, unless otherwise noted, orally):

	2,4-D	2,4,5-T
Rats	620 (320-954)	481 (313-739)
Guinea pigs	848 (604-1190)	750 (500-1000)*
Rabbits	424 (252-712)	712 (500-1000)*
Mice	713 (500-1000)*	940 (674-1312)
Chicks	2000 (1350-2760)	not determined

The LD_{50} values of other forms of the two chemicals (free acids, salts, other esters) fell within the above ranges suggesting that there are no substantial differences in their toxicity. Later investigations

[a] Potentiation means increase of activity--here, toxicity--above that of the sum of the two compounds applied singly.

[b] In most toxicological studies on herbicides, the doses are expressed in weights of the actual active compound, not as acid equivalents. In the case of the butyl esters, the acid equivalent values for 2,4-D and 2,4,5-T would be about 10 and 20 percent less, respectively.

have, in general, borne out these results. Some studies suggest, however, that esters with a large esterifying group, such as the propyleneglycolbutyl ether esters, are more toxic than those with a small group, like the butyl esters.

Cattle appear to respond similarly to small laboratory animals in terms of acute toxicity (Rowe and Hymas, 1954). Pigs are apparently more sensitive (Björklund and Erne, 1971).

In addition to the determinations of LD_{50} there are numerous reports on effects of 2,4-D and 2,4,5-T when administered to warm-blooded animals over longer periods of time. The results are sometimes contradictory. Thus, Drill and Hiratzka (1953) reported that 20 mg/kg of 2,4-D or 2,4,5-T, given 5 times weekly, caused death in dogs but Hansen et al. (1971) were unable to reproduce this result. The reasons are not clear; they may reside in differences between different breeds. On the whole, however, administration of the same amount in repeated, smaller doses has less toxic effects than a single large dose. In feeding studies with cattle, sheep, and chickens, no ill effects were noted at daily levels of 50 mg/kg of 2,4-D or 2,4,5-T daily given for as long as a year; 100 mg/kg/day caused some weight loss or reduced weight gain and other minor effects in some of the animals, while 250 mg/kg/day proved to be toxic (Palmer and Radcleff, 1969). 2,4-D and 2,4,5-T thus belong to those toxic materials which have only a limited cumulative action. The reason is undoubtedly that in most animals they are rapidly removed from the body, mainly in the urine (see below).

A number of studies have been conducted with wild animals. Reindeer were found to have a susceptibility similar to that of other mammals (Erne, 1972). Wild animals collected from areas treated with phenoxyacetic compounds had some, although low, residues in liver and kidney, but no pathologic changes were found (Erne, 1971). The LC_{50} (concentration in drinking water) for bobwhite quail, Japanese quail, pheasant and mallard was over 5000 ppm of 2,4-D as butoxy-ethanol ester and dimethylamine salt (Heath et al., 1972); this is approximately equivalent to between 1000 and 2500 mg/kg/day. Some bobwhite quail, coturnix quail, and pheasant died after 10 daily feedings with 2500 or 5000 ppm of the same preparations; higher levels of mortality but not a complete kill resulted from longer feeding periods (Bureau of Sport Fisheries and Wildlife, 1962, 1963, 1964).

Lutz and Lutz-Ostertag (1970) sprayed an incompletely specified formulation of 2,4-D on eggs of pheasant, red partridge, and grey partridge at a rate equivalent to a field application of one-half to one lb/acre, and reported mortality rates of 77, 43, and 77 percent, respectively, and paralysis and morphological anomalies in the surviving offspring. But while some illustrations of control embryos are shown, no numerical data on controls (untreated eggs) are given. Somers (1972), after spraying pheasant eggs with a formulated mixture of 2,4-D and 2,4,5-T as the isooctyl esters (1:1) at 10 lb/acre total or with Agent White (Tordon 101) at 0.25 and 2.5 lb/acre, found numerous eggs with dead and malformed embryos (38 to 51 percent) and low hatchability of the fertile eggs (61 to 59 percent), but there were no differences between treated and control eggs.

There are only limited studies on pathological or biochemical changes associated with 2,4-D and 2,4,5-T poisoning in animals (Björklund and Erne, 1971) and they do not permit us to pinpoint any particular effect as the primary "lesion" caused by these compounds.

2,4-D and 2,4,5-T have limited retention times in mammals and birds, and are excreted mainly in the urine in unchanged form. The two substances are strong acids, and this behavior in the organism is characteristic of such acids. After a single administration, the maximum in blood and organs is reached in about 2 to 6 hrs., followed by a sharp drop and then a slower decline. After repeated administrations of nontoxic or only mildly toxic doses--in some experiments, up to 100 days--the situation was similar, with no evidence of accumulation or longer term retention, but with evidence of transfer of small amounts into milk and eggs. 2,4,5-T has somewhat but not greatly longer retention times than 2,4-D. Examples are compiled in Table II C-3. Only when animals were acutely poisoned with several large doses (sheep; 250 mg/kg/day for 4 to 6 days) and analyzed immediately after killing or in autopsy were high levels found in kidneys (up to 368 ppm), liver and fat (about 80 ppm) (Clark and Palmer, 1971). When a single dose of an ester was administered, most of the excretion was in unchanged form, but after higher doses and repeated administrations, increasing amounts were excreted as the free acid, and in animals acutely poisoned with an ester most of the excreted material was in the free acid form (Clark and Palmer, 1971). The results indicate that the ability of the organism to hydrolyze the ester increases with increasing time and dose.

The situation, as just outlined, holds for rats, cattle, sheep, and chickens. Elimination in the pig is somewhat slower, the difference being particularly evident in the blood plasma (Björklund and Erne, 1971), and in dogs the retention times in the body were markedly longer than in rats while the urine contained degradation products of the herbicide, indicating a larger amount of metabolism (Piper *et al.*, in press; see Table II C-4). These characteristics quite likely account for the greater toxicity of 2,4-D and 2,4,5-T in pigs and particularly in dogs. The behavior of 2,4,5-T in man appears to be much more similar to that in the rat than in the dog (Gehring *et al.*, in press; see Table II C-4).

Numerous laboratory studies have been conducted on the toxicity of various forms of 2,4-D and 2,4,5-T to fish and other aquatic organisms. A number of examples are given in Table II C-5. It appears that 2,4-D and

Table II C-3

Herbicide residues in tissues of animals fed 2,4-D or 2,4,5-T.*

Animal	Compound, dosage, and application	Duration of treatment	Time of determination after end of treatmt.	Level in ppm (fresh weight)						
				Blood plasma	Muscle	Liver	Kidney	Fat	Milk	Eggs
Rats	2,4-D TEA[a]; 100 mg/kg, oral	One dose	6 hours[b]	150	23	90	250	-[d]	-	-
			6 hours[c]	70	14	35	145	-	-	-
			24 hours[b]	2	2	5	27	-	-	-
			24 hours[c]	1.5	0.6	3	15	-	-	-
	2,4-D TEA; 1000 ppm in drinking water	2 months	Irregular intervals	10[b]	7	25	45	1.5	-	-
				5[c]	3	3	15	-	-	-
Cattle[e]	2,4-D; 2000 ppm in feed	30 days	Within 24 hrs.	-	<0.025	0.2[f]	4[f]	0.05	-	-
	2,4-D; 1000 ppm in feed	2-3 weeks	Within 24 hrs.	-	-	-	-	-	0.05[f]	-
			3 days	-	-	-	-	-	<0.05	-
	2,4,5-T; 1800 ppm in feed	30 days	Within 24 hrs.	-	0.9	6[f]	7[f]	1.7	-	-
	2,4,5-T; 1000 ppm in feed	2-3 weeks	Within 24 hrs.	-	-	-	-	-	0.4	-
			3 days	-	-	-	-	-	<0.05	-
Sheep	2,4-D; 2000 ppm in feed	4 weeks	Within 24 hrs.	-	0.06	0.98	9.17	0.10	-	-
			7 days	-	ND[d]	0.27	0.37	0.15	-	-
	2,4,5-T; 2000 ppm in feed	4 weeks	Within 24 hrs.	-	1.0	2.29	27.23	0.25	-	-
			7 days	-	ND	ND	<0.05	<0.05	-	-
Pigs	2,4-D TEA; 100 mg/kg, oral	One dose	6 hours	20	21	115	190	3	-	-
			24 hours	27	3	27	36	2	-	-
			48 hours	6	2	6	10	-	-	-
			72 hours	4	1.6	4	5	-	-	-
	2,4-D TEA; 100 mg/kg, oral	30 days	24 hours	7	1.5	10	17	0.5	-	-
	2,4-D TEA; 500 ppm in feed twice daily	2 months	Irregular intervals	22	2	6	12	1.3	-	-
Chickens	2,4-D TEA; 200 mg/kg, oral	1 day	6 hours	100	3.5	80	120	1.1	-	<0.1[g]
			24 hours	15	1.5	25	80	-	-	0.2[g]
			48 hours	5	1.2	3	7	-	-	0.2[g]
	2,4-D; 1000 ppm in drinking water	2 months	Irregular intervals	10	3	15	20	1.0	-	1.5[h] 0.2[i]

*Data for rats, pigs, chickens from Erne (1966) and Björklund and Erne (1971), for cattle from Getzendaner (1973), for sheep from Clark et al. (1971).

a - TEA = triethanolamine salt, BE = butyl ester
b - = males
c - = females
d - = not determined, ND - not discovered
e - levels expressed as ppm in tissue per 1000 ppm in feed
f - small amounts of the corresponding chlorophenol found
g - in yolk; not detectable in white
h - in yolk
i - in white

Table II C-4

Fate of 2,4,5-T in Rat, Dog and Man
(Fed a Single Oral Dose of 5 mg/kg)*

	Rat	Man[a]	Dog
Plasma half-life[b] (hrs)	7	23	69
Body half-life (hrs)	18	30	125
Urinary metabolites	None	None	Present
Percent excreted in urine	83 (6 days)	88 (4 days)	38 (6 days)
Percent excreted in feces	3 (6 days)	<1 (2 days)	17 (6 days)

* After Gehring et al., in press, and Piper et al., in press.

[a] Five volunteers

[b] Half-life is the time required for the disappearance of one-half of the maximum observed level.

Table II C-5

Effect of 2,4-D and 2,4,5-T on Aquatic Organisms

Organism	Chemical[a]	Exposure hours	LC50[b] ppm	Reference
Bluegill	2,4-D AA, DMA and similar	24	166-900	Hughes and Davis, 1963, 1966
		48	166-840	
	2,4-D BEE	24	2.1	
		48	2.1	
	2,4-D BuE	24	1.3-10	
		48	1.3	
	2,4-D PGBE	24	2.1	
		48	0.9-2.1	
	2,4,5-T DMA	24	53.7-144	
	2,4,5-T PGBE	24	17	
	2,4-D PGBE	long-term	c	Cope *et al.*, 1970
Rainbow trout	2,4-D PGBE	48	1.1	Bohmont, 1967
	2,4,5-T Ac	24	12	Alabaster, 1969
	2,4,5-T Ac	48	1.3	Bohmont, 1967
Harlequin fish	2,4-D Na	24	1,160	Alabaster, 1969
	2,4-D BuE	24	1	
	2,4,5-T BuE	24	1	
Water flea (Daphnia)	2,4-D Acid	48	>100	Sanders, 1970a
	2,4-D DMA		4.0	
	2,4-D BEE		5.6	
	2,4-D PGBE		0.1	
Seed Shrimp (*Cypridopsis vidua*)	2,4-D DMA	48	80	
	2,4-D BEE		1.8	
	2,4-D PGBE		0.32	
Scud (*Gammarus fasciatus*)	2,4-D Acid	48	3.2	
	2,4-D DMA		>100	
	2,4-D BEE		5.9	
	2,4-D PGBE		2.6	
Sowbug (*Asellus brevicaudus*)	2,4-D DMA	48	>100	
	2,4-D BEE		3.2	
	2,4-D PGBE		2.2	
Crayfish (*Orconectes nails*)	2,4-D DMA BEE, PGBE	48	>100	
Western Chorus Frog	2,4-D DMA	96	>100	Sanders, 1970b

a - AA alkanolamine salts; Ac = acid; BEE butoxyethanol ester; BuE = butyl ester; DMA dimethylamine salt; PGBE propyleneglycolbutyl ether ester

b - Where a range is shown, it refers to different preparations or different experiments

c - Outdoor experiments: 10 ppm caused 50% death in 10 days; 5 ppm and less caused no mortality.

2,4,5-T as acids and salts are not very toxic to aquatic organisms; however, certain esters are toxic at about one ppm and even 0.1 ppm in the water. There is considerable and unexplained variation between experiments and within the same experiment, and between different samples of the same chemical. It should also be realized that laboratory studies on toxicity can be misleading. In the case of aquatic animals maintained in containers the chemicals can be bound only to the animals and the sides of the container whereas in a pond, river, etc. they are also bound to soil, mud, any suspended materials, and plants. An outdoors experiment with bluegill indicated that the toxicity of one particular chemical, the 2,4-D propylene-glycolbutyl ether ester, was considerably less than in the laboratory (see Table II C-5). Unfortunately, there seem to be no studies on metabolism and excretion in aquatic animals. Bioconcentration in such animals under field conditions does not seem to occur. After treatment of a pond with as much as 30 lb/acre 2,4-D, fish contained a residue of 0.3 ppm while the residue in crab was below the detection limit of 0.8 ppm (Coakley et al., 1964).

(f) Effects in Man.

The literature contains a number of descriptions of acute poisoning in man by 2,4-D and to a lesser extent by 2,4,5-T. These include accidents and attempts at suicide. The doses ingested were quite high but varied in wide limits. Thus, in one fatal case the estimate was 1200 to 1800 mg/kg, in a second one 80 mg/kg. In another case, however, 110 mg/kg resulted in toxicity but the patient survived. Evaluation of the fatal dose is made more difficult because ingestion was followed by vomiting in some of the cases. It has been inferred that about 50 to 100 mg/kg of 2,4-D are acutely toxic for man but this is hardly more than a "guesstimate." On the other hand, lower amounts have been ingested or otherwise absorbed over some periods of time with no apparent adverse effects. E. J. Kraus, one of the earliest investigators of 2,4-D, consumed 100 mg of the substance daily for 30 days; another individual ingested 500 mg daily for three weeks, in either case with no perceptible consequences. Assuming a weight of 150 lb, the daily doses would have been about 1.4 and 7 mg/kg, respectively. Two patients were treated (unsuccessfully) with 2,4-D against coccidioidomycosis. One received a total of 12.7 g. of the sodium salt over a period of 34 days. Intravenous doses of 2 g. were tolerated without adverse response whereas a dose of 3.6 g. caused nervous responses for a period of 48 hrs., but there were no other, more persistent adverse effects.

A number of health studies on groups of persons who may have been chronically exposed to 2,4-D and 2,4,5-T have been carried out. In the case of workers involved in the manufacture of 2,4,5-T, certain signs (chloracne, often accompanied by hyperpigmentation and hirsutism) are attributable to TCDD which occurs as a contaminant in the manufacture of 2,4,5-trichlorophenol, the precursor of 2,4,5-T (Poland et al., 1971). TCDD will be discussed in Section II C (4) of this chapter. Excluding such cases, the main findings are as follows:

(1) In a very brief paper, lacking numerical data and many important details, Fetisov (1966) describes some results of health examinations on 105 workers engaged in production of 2,4-D including salts and esters, and on 45 persons engaged in aerial spraying of 2,4-D type herbicides in agriculture. Symptoms which were reported and which appeared to increase with the degree of exposure were fatigue and headaches at the end of the work day, loss of appetite, pains in the stomach and kidney regions, and occasionally symptoms in the upper respiratory tract. The symptoms usually disappeared by the next morning. Special tests showed reduced taste and smell sensations. No examinations on comparable control populations are mentioned. The concentration of the chemicals in the air of the factory was extremely high, containing up to 28 to 44 mg/m^3.

(2) Poland et al. (1971) conducted health examinations and clinical tests on 73 workers involved mainly in the production of 2,4,5-T for periods of less than one year to more than 13 years. No significant increases in abnormal function of the cardiovascular, pulmonary, intermediary metabolic, and hematological systems were found, but some neurological deficiencies were noted (six cases of decreased hearing, one of diminished proprioception, two without ankle jerks). However, since no comparable control population was studied, it is not possible to say whether this prevalence was normal or abnormal in this population. A personality inventory test showed correlation only with chloracne, most probably a result of TCDD toxicity.

(3) Long et al. (1969) carried out a comparative investigation of two groups of farmers in Johnson County, Iowa, who differed greatly in the use of insecticides and herbicides on their land. One group (15) were high users; their total usage was over 4700 lb insecticides and over 5300 lb herbicides, of the latter almost 3000 lb 2,4-D or 2,4-D formulations. The other group (18) were low users; their usage figures were 380--290--about 180 lb, respectively. Otherwise, the two groups exhibited no obvious differences. The subjects were given comprehensive medical examinations, their medical histories were studied, and they were subjected to 16 clinical laboratory tests and to analyses of some of the pesticides in their blood. The blood levels were not correlated with high versus low pesticide use, but correlations with several other clinical characteristics were found. In the case of 2,4-D, the only such correlation was high serum albumin values in the high use group. The authors emphasize that their results must be interpreted with great caution.

(4) In a study (Sundell, 1972) of mortality, general and from tumors and lung cancer (defined according to the World Health Organization Diagnosis Register, Chapters II and A50, respectively), among Swedish State Railways workers who had been engaged in herbicide spraying for at least one season (46 days) no difference from the mortality rates representative of the whole country were found in a group (194 individuals) that had been exposed only to phenoxy herbicides (mainly 2,4-D and 2,4,5-T). A significant ($p<0.02$) increase of cancer deaths was found in individuals exposed to amitrol (a chemically different herbicide), whether alone or in combination with other

herbicides, and there was an indication that this was correlated with relatively heavy exposure. The study included individuals exposed in the same year, and 3 or 5 years earlier.

(5) A health study of workers who had been engaged in application of 2,4-D and 2,4,5-T preparations along the Finnish State railroads was conducted in 1972 (Working Group on the Impact of Herbicides on Human Health, 1973). A group of 180 workers in the age brackets 10-19 to 60-69 (mostly, 30-59), mostly males, who had been involved in herbicide spraying mainly from backpack sprayers and to a lesser extent with motorized or other mechanized equipment, and for periods of less than one week to over 8 weeks, were studied by means of an extensive questionnaire and compared with a control population, i.e. workers who had not been in contact with herbicides. Thirty individuals were subjected to a "preliminary" medical examination which included tests on the function of liver, kidney, thyroid, and respiratory organs, and blood sugar; 18 individuals were given additional tests on the functioning of the nervous system. In addition, a total of about 2000 cases in the demographic records were evaluated as to mortality rate and cause. These included workers who had been engaged in herbicide applications on railroads and roads, and around waterworks and a power plant. They were divided by exposure period (2 to 7 weeks, and 8 weeks or more), by age groups, and by death causes (cancer, respiratory and blood diseases, death from natural causes), and were compared with the total Finnish population and the part engaged in gainful employment. Among the persons engaged in herbicide spraying there were complaints of the same kind as reported by Fetisov (1966), i.e. fatigue, headache, stomachache, irritation of the respiratory organs, plus instances of skin irritation, rash, and eye irritation. However, with the possible exception of headaches, these did not exceed the incidence in the control population. No significant differences were found in mortality rates and causes, or in the various laboratory tests, but the incidence of disturbances in the electroencephalogram, indicative of disturbances in the functioning of the nervous system, was two times higher than in those workers who were not exposed to substances affecting the nervous system. The statistical significance in this case was between 5 and 10 percent. While this is outside the generally accepted level of statistical significance (<5 percent) it is indicative and the Working Group recommends further studies, with larger numbers of subjects. On the other hand, it states that the observed deviations were mild and did not constitute an illness as such.

(6) A recent study of employees in a 2,4,5-T manufacturing plant in the U.S. (C. G. Kramer and M. G. Ott, Industrial Hygiene and Medical Department, The Dow Chemical Company; unpublished) identified three populations exposed to 2,4,5-T: (a) 130 employees with more than six months exposure, (b) 35 employees currently working in areas of 2,4,5-T exposure, and (c) 64 employees whose respiratory exposure to 2,4,5-T could be estimated with considerable accuracy and ranged from between 1 and 99 mg total exposure

to more than 10,000 mg. The results of a physical examination including extensive chemical analyses, combined with a review of medical and exposure histories, failed to produce evidence of adverse effects resulting from their work exposure, at a 5 percent level of significance, in any of the three groups as compared with a control population of 4600 individuals which, in turn, did not vary significantly from the general population.

All available studies are cross-sectional; the exposed populations were examined once or in some cases twice, and their past medical histories evaluated. No longitudinal studies, in which the same persons would be observed at regular intervals over longer periods of time, appear to have been made. Thus, temporary and also delayed effects may have been overlooked (there is, however, no evidence for delayed effects in animal work). But with this reservation the results of all these studies do not provide any conclusive evidence for serious adverse effects of 2,4-D, 2,4,5-T and their derivatives on the health of humans exposed to these compounds on a daily basis, sometimes for years. The results of the work of Fetisov (1966) cannot be properly evaluated since, as already stated, it is not clear whether appropriate controls were studied. The exposure level of at least part of the subjects of this study was unusually high.

A number of cases are reported in the literature where skin exposure to 2,4-D (as acid, ester, or salt) resulted in disorders of the peripheral nervous system. The symptoms included vomiting, head- and stomachaches, reduced sensory perception mainly in the extremities, and limb paralysis, and lasted for weeks and months; in some cases, recovery was incomplete after several years. The exposures, where adequately known, were quite heavy, for example, spilling of 10 fluid ounces of a 10 percent solution of a 2,4-D ester on the forearms followed on another day by wetting of the legs; or drenching by sprays of solutions of 2,4-D or derivatives of over 25 to over 40 percent concentration, in some cases again on repeated occasions. Several of the authors stress that the situations were unusual, and suspect predisposition of the subjects to disorders of this kind. The total number of the cases reported is less than ten; comparing them with the results of the group studies summarized above and considering the wide use of 2,4-D it does not appear justified to consider this a general effect of the herbicide. Fullerton (1969), in a review on effects of industrial chemicals on peripheral neuropathy, considers 2,4-D as having neuropathic effects only after a gross overdose.

Table II C-6 gives toxicity ratings for 2,4-D and 2,4,5-T for humans, compared with a number of other chemicals. The two herbicides fall in the two medium classes; they are compounds which are distinctly toxic but which must be consumed in quite substantial quantities to have any overt effect. They are clearly much less toxic than well-known poisons such as strychnine and arsenic. The higher rating of 2,4-D as

Table II C-6

Toxicity Ratings of Herbicide Components and Some Other Substances
(Source: Gleason *et al.*, 1969)

Herbicide[a]	Component of Agent	Toxicity Rating
Cacodylic Acid	Blue	3
2,4-D	White, Orange	4
2,4,5-T	Orange	3[b]
Comparative Substances		
Strychnine		6
Arsenic		5
Aspirin (acetylsalicylic acid)		4
Caffeine		4
DDT		4
Belladonna leaf		4
Diesel fuels		3
Alcohol (ethanol, ethyl alcohol)		2
Calcium carbonate (chalk)		1

Toxicity Rating

The toxicity ratings are based on mortality (not morbidity or other effects) after a single dose and represent an estimate of the probable or mean lethal dose. Most values are extrapolations from LD_{50} determinations in animals (application by mouth or stomach tube) but whenever available, clinical data and even clinical impressions for humans have been given precedence.

Toxicity Rating or Class	Probable Lethal Dose (Human): mg or gram/kg	For a 150 lb (70 kg) human
6	less than 5 mg/kg	a taste (less than 7 drops)
5	5-50 mg/kg	between 7 drops and 1 teaspoonful
4	50-500 mg/kg	between 1 teaspoonful and 1 ounce
3	500 mg to 5 gm/kg	between 1 ounce and 1 pint (or 1 lb)
2	5-15 gm/kg	between 1 pint and 1 quart
1	above 15 gm/kg	more than 1 quart

[a] For approximate rating of picloram, see Section II C(1).

[b] Compare text.

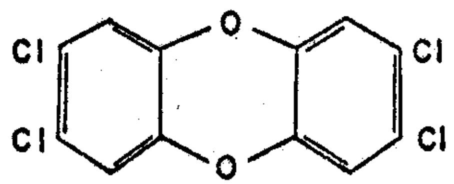
compared to 2,4,5-T is probably due to the fact that more cases of 2,4-D than of 2,4,5-T poisoning in humans are known, but this is undoubtedly a reflection of the fact that the former herbicide is more in use than the latter. Experiments with warm-blooded animals do not indicate any consistent differences in the toxicity of the two compounds; on this basis, both would appear to be on the borderline of toxicity classes 4 and 3.

(4) TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin), a Contaminant of 2,4,5-T and Other Dioxins

In the 1950's and 60's, manufacturers of chlorinated phenols and of 2,4,5-T in the U.S. and Germany experienced outbreaks of a skin disease, chloracne, among their workers.[a] During the same period outbreaks of mortality, associated with severe edema, occurred among broiler chickens in various parts of the U.S. These were traced to a "chick edema factor," toxic substance(s) present in various materials unrelated as to origin: lipid residues from the manufacture of fatty acids that were used as chicken feed ingredients; food grade fatty acids themselves; some crude vegetable oils; and soapstock, a byproduct from refining such oils.

In subsequent studies it became apparent that the causal agents for both the chloracne and the chick edema disease were polychlorodibenzo-para-dioxins.

Chlorodibenzo-para-dioxins consist of two benzene rings linked together by two adjacent oxygen bridges, and having one to eight chlorine atoms attached. At least theoretically, 75 different chlorodibenzo-para-dioxins can be postulated. So far, about 10 have been synthesized, and one or more have been found to occur in such items as food, animal feeds, and 2,4,5-T. The most common dioxin in 2,4,5-T is 2,3,7,8-tetrachlorodibenzo-para-dioxin or TCDD. Our discussion deals primarily with TCDD and its presence in 2,4,5-T. It is, however, not the only toxic chlorodibenzodioxin, and the manufacture of 2,4,5-T is not the only industrial source of these compounds.



TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin)

[a] The disease had been described in 1899 and erroneously attributed to free chlorine; hence the name.

(a) Physical and Chemical Properties

TCDD arises during the hydrolysis of tetrachlorobenzene to form 2,4,5-trichlorophenol, the industrial precursor of 2,4,5-T. The hydrolysis is carried out under alkaline conditions, at high temperatures, and under pressure, conditions each of which, unless very carefully controlled, is favorable to the formation of the chlorodioxins.

The production of 2,4-dichlorophenol, the precursor of 2,4-D, does not involve any of the conditions necessary for 2,4,5-trichlorophenol production, nor does production of picloram. Neither 2,4-D nor picloram were found to contain TCDD, at least when analyzed with methods permitting detection to a limit of 0.05-0.02 ppm.

TCDD is a solid which is very insoluble in water (at 77°F = 25°C, 0.0002 ppm or 0.2 parts per billion), very slightly soluble in fats (44 ppm in lard oil), slightly soluble in hydrocarbons (570 ppm in benzene), and somewhat more soluble, but still not very highly so, in chlorinated organic solvents (1400 ppm in ortho-dichlorobenzene). The solubility in Agent Orange is 580 ppm. Like other chlorodioxins, TCDD is stable to heat, acids and alkali. For thermal decomposition, at least about 800°C (1500°F) is required.

As will be seen in the next two sections, TCDD exerts its biological effects at extremely low concentrations. This has posed serious limitations on analytical work with the substance. The sensitivity limit of previous methods has been in the range of 0.05 to 0.02 ppm (in one case, down to 0.001 ppm; Woolson et al., 1973)--inadequate for a number of purposes. Baughman and Meselson (1973a, 1973b) have recently described a method which permits determination to a level of about 0.000003 ppm or 3 ppt (parts per trillion) and is thus a great step forward where measurements of very small levels of TCDD are critical.

(b) Fate in Plants and Soil

Studies on the behavior of TCDD in the environment have in the last 3-4 years been a major research effort of the U.S. Department of Agriculture (Pesticide Degradation Laboratory, Beltsville, Maryland), partly in cooperation with other laboratories. They have been summarized by Kearney et al. (1973). The principal results are the following:

(1) TCDD in alcoholic solution was rapidly decomposed by light but in aqueous suspension and on soil or bare surfaces such a photodegradation was negligible.

(2) Approximately half of TCDD persisted in two moist soils after one year under laboratory conditions, regardless of the amount applied (1, 10 and 100 ppm) and the soil type.

(3) Downward movement of TCDD did not occur in a wide range of soil types, including sandy soils which are generally prone to leaching.

(4) In a sandy soil to which 2,4,5-T had been applied at high rates (942 lb/acre in 1962-64, or 584 lb/acre in 1964-66, or 183 lb/acre in 1968-69) no TCDD was found when the soil was sampled and analyzed in December 1970. The samples consisted of 36 in. (about 90 cm) cores subdivided into 6 in. (15 cm) increments; the detection limit was between 0.001 and 0.004 ppm. Assuming that all TCDD remained in the uppermost 6 in. of the soil--quite reasonable in view of the lack of downward movement just mentioned--the failure to find TCDD would mean that the 2,4,5-T used contained less than 2 ppm of TCDD, or else that the TCDD had been at least partially broken down in the soil (see Woolson et al., 1973).

(5) TCDD was taken up and transported into the tops of young oat and soybean plants grown for two weeks on a nutrient solution with 0.16 ppm TCDD. The maximal concentration observed in the plants was 1.5 ppm on a dry weight basis; this corresponds to less than 0.15 ppm of wet weight. In most cases, the concentration was less and decreased further with time. Uptake and transport into the tops was also observed in plants grown on a sandy loam containing 0.06 ppm TCDD. The maximal concentration found in oats was 0.132 ppm dry weight or less than 0.013 ppm wet weight; in soybean, it was 0.057 and less than 0.006 ppm, respectively. As the plants grew to maturity, the TCDD level decreased, and no TCDD could be detected (limit, <0.01 ppm) in either the vegetative parts or the seeds of oat, while only 0.005 and 0.004 ppm (dry weight basis), respectively, could be found in soybeans. The total amount in soybean seeds was only 5 to less than 2 percent of that in the vegetative tissue. The results thus indicate that the uptake of TCDD was sluggish and decreased with time, and that there was no accumulation (that is, no uptake above the external concentration) and little redistribution from older to younger parts of the plant (Isensee and Jones, 1971).

(6) When applied to the foliage, TCDD was not translocated from the point of application to other parts of oat and soybean plants. Despite the very low water solubility over 50 percent of the applied amounts could be washed off with water 2 hours after application, and the authors believe that some volatilization may also have occurred, particularly in the case of oats (Isensee and Jones, 1971).

(7) Analyses of 19 carcasses of bald eagles, representative of the top of the food chain, yielded no detectable (<0.05 ppm) dioxin (Woolson et al., 1973).

Model experiments on the environmental behavior of TCDD, using "closed ecosystems" in aquaria, were conducted by Matsumura and Benezet (1973). Their findings indicate that bioconcentration of TCDD in the food chain was less than that of DDT, probably because of its very low water solubility and relatively low fat solubility. The most efficient "concentrators" among the organisms tested were mosquito larvae. In agreement with other authors (see above), movement in soil or between different soils (from sand to organic soil) was found to be very limited. On the other hand, few microorganisms were found that would degrade TCDD. The efficiency of degradation was low and could not be increased by various manipulations of the cultural conditions.

(c) Formation of TCDD from 2,4,5-T in the Environment

Concern has been voiced that TCDD may be formed from 2,4,5-T and 2,4,5-trichlorophenol under conditions that may be encountered in nature or created by human activity, e.g., under the influence of radiation or by burning of materials containing 2,4,5-T. Irradiation with sunlight or "simulated sunlight" (ultraviolet light known to have the same photochemical effects as sunlight) did not result in formation of TCDD from 2,4,5-T (Kearney et al., 1973; Crosby et al., 1973, Plimmer, 1973). In contrast, heating of the sodium salt of 2,4,5-T to 300-350°C (572-662°F) in an open tube for 30 minutes to 12 hours resulted in the formation of 1000 to 3000 ppm of TCDD (Baughman and Meselson, personal communication). In this connection it is, however, important to realize that TCDD formation is a so-called bimolecular reaction in which the relative yield decreases with decreasing concentration of the parent substance(s). Thus, TCDD yields should be much less if plant material containing 2,4,5-T is heated than in laboratory experiments with concentrated 2,4,5-T or its derivatives.

The sole report on formation of TCDD from 2,4,5-T treated plant material is by Buu-Hoi et al. (1971). Unfortunately, no details on the amount or kind of plant material, its content of 2,4,5-T, or conditions and duration of heat treatment are given; it is merely stated that TCDD was produced when "material from vegetation pretreated with 2,4,5-T" was subjected to "more or less extensive combustion." A review of the identification procedure of Buu-Hoi and coworkers by Langer et al. (1973) indicated strongly, however, that the product measured in these experiments was not TCDD.[a]

---

[a] Buu-Hoi et al. (1971) also reported formation of as much as 50,000 ppm (5 percent) of TCDD from heating 2,4,5-T to 500-600°C (900-1100°F), and even of 150,000 ppm (15 percent) by similar treatment of the sodium salt of 2,4,5-T. These yields are vastly larger than those of Baughman and Meselson, and the work is in need of confirmation.

(d) Other Potential Sources of TCDD, and Other Chlorodioxins

As pointed out, TCDD arises as a byproduct in the manufacture of 2,4,5-trichlorophenol. While the use of this trichlorophenol in 2,4,5-T production is a major one the compound is also utilized for other purposes, such as for slime control and as a defoaming agent in paper and cardboard manufacture. Of six samples of commercial 2,4,5-trichlorophenol, three were found to contain between 0.07 and 6.2 ppm of TCDD (Firestone et al., 1972). With the trichlorophenol, TCDD may get into the various products and thence into the environment. On the other hand, formation of TCDD from trichlorophenol under the action of sunlight, simulated sunlight, or by microbial condensation in soil has not been observed (Kearney et al., 1973; Plimmer et al., 1973; Crosby et al., 1973).

As also pointed out earlier, TCDD is the most toxic among the chlorodioxins studied, but is not the only one. Hexachlorodioxin and probably some tri- and heptachlorodioxins are also highly toxic substances. Hexachlorodibenzo-para-dioxin at daily doses of 0.01 mg/kg caused reduction in the rate of body weight increase in pregnant rats and their fetuses and a ten times higher dose caused abnormalities in some fetuses; it also induced edema in chickens at 0.01 mg/kg per day (Schwetz et al., 1973). These doses are roughly 10 to 30 times higher than TCDD doses causing similar effects. In contrast, 2,7-dichloro-, 1,3,6,8-tetrachloro- and octachlorodioxin had very low toxicity, and no demonstrable teratogenicity at the highest doses tested. The LD_{50}'s were over 100,000 times higher than those for TCDD, and no teratogenicity was found at 100 mg/kg/day.

The higher chlorodioxins (6, 7, and 8 chlorine atoms) may be expected to arise in the production of pentachlorophenol. Pentachlorophenol is produced in the U.S. by chlorination of phenol at nearly atmospheric pressure, without alkalinity, and at temperatures of about 200°C (350°F). However, the production of sodium pentachlorophenate involves the same conditions (high temperature, pressure, alkalinity) as that of trichlorophenol. Hexachlorodioxin has indeed been found in almost all samples of commercial pentachlorophenol tested, along with hepta- and octodioxins, the latter two at levels of up to 1000 ppm (Firestone et al., 1972; Plimmer, 1973). Formation of hexa-and heptachlorodioxin has been observed when chips of pentachlorophenol treated plywood were burned (Crosby et al., 1973), and hexa- and octo-chlorodioxin were formed from pentachlorophenol under the influence of ultraviolet light (Crosby and Wong, in preparation). TCDD has to date not been found in pentachlorophenol (Woolson et al., 1972; Firestone et al., 1972) although the latter may also contain small amounts of trichlorophenol.

Pentachlorophenol is extensively used, for the same purposes as trichlorophenol but also as a wood preservative, for the preservation of hides, starches and glues, in paper designed for contact with aqueous and fatty foods, as antioxidant in rubber articles used in producing, processing or holding food, and in manufacture of certain plastics used in the food industry. Production in the U.S. in 1967 was 44,000,000 lb. and in 1970, 47,000,000 lb., most of the use being as wood preservative. In comparison, production of 2,4,5-trichlorophenol (including salts) in 1967 was 25,000,000 lb. (no data for 1970), and of 2,4,5-T including salts and esters in 1967, 42,000,000 lb. and in 1970, 12,300,000 lb. (U.S. Tariff Commission, 1967 and 1970). Thus, the likelihood that hexachlorodibenzo-para-dioxin enters the environment from pentachlorophenol is real unless production methods are used which reduce the contamination of these substances to acceptable levels. One U.S. manufacturer now produces a pentachorophenol with not more than 30 ppm octochlorodioxin, not more than 1 ppm hexachlorodioxin, and no TCDD at the detection limit of 0.05 ppm. The content of TCDD in 2,4,5-T presently manufactured in the U.S. does not exceed 0.05 ppm.

(e) Effects and Fate in Animals, Including Man

LD_{50} values that have been reported for TCDD are summarized in Table II C-7. The data for dogs (beagles) are based on only two animals per dose level and are thus preliminary.

In longer-term feeding studies, Harris et al. (1973) found that six weekly doses of 0.005 mg/kg TCDD caused decreased weight gain in rats, and so did 30 daily doses of 0.001 mg/kg, while 6 x 0.001 mg/kg and 30 x 0.0001 mg/kg had no such effect (but the latter still caused a decrease in thymus weight); Norback and Allen (1973) reported that 0.001 mg/kg per day caused 50 percent mortality in rats in 21 days. In guinea pigs, eight weekly doses of 0.002 mg/kg reduced the rate of weight gain, but eight weekly doses of 0.00004 mg/kg did not; in mice, the respective levels were 0.025 mg/kg and 0.005 mg/kg (Harris et al., 1973). In chickens, daily feedings with 0.001 mg/kg TCDD caused edema while 0.0001 mg/kg did not (Schwetz et al., 1973). *Macaca mulatta* monkeys which were fed "toxic fat," i.e., crude industrial fat containing the chick edema factor, survived 100 days of such feeding at a level that caused 50 percent mortality in chickens, but died when fed with higher levels, the survival time being inversely related to the level of "toxic fat" in the diet (Allen and Carstens, 1967; Norback and Allen, 1973). However, the chemical nature of the toxic material in the "toxic fat" was not identified so that it is not entirely certain that it was TCDD.

The warm-blooded animals so far tested exhibit a wide range of sensitivity to TCDD. Guinea pigs and chickens are most sensitive; mice, rabbits, and dogs least sensitive; rats and (if the "toxic fat" factor was TCDD) *Macaca* monkeys occupy an intermediate position.

Toxicity of TCDD in aquatic organisms was studied by Miller et al. (1973). Young coho salmons, kept in containers with static water and exposed for 24, 48 or 96 hours to 0.000056 ppm TCDD in the water had died by the end of 40 days. Exposure to one tenth, one hundredth, and one thousandth that level for 24 hours or longer caused 55, 12, and

Table II C-7

LD_{50} values for single doses of TCDD

Animal	Sex	Application	LD_{50}, mg/kg	Reference
Rats	Male	Oral	0.022	Schwetz *et al.*, 1973
	Female	Oral	0.045	Schwetz *et al.*, 1973
	Mixed	Oral Intubation	0.100	Harris *et al.*, 1973
Mice	Mixed	Oral	a	Schwetz *et al.*, 1973
	Mixed	Oral Intubation	Between 0.100 and 0.200	Harris *et al.*, 1973
Guinea pigs	Male		0.0006[b]	Schwetz *et al.*, 1973
	Male		0.0021[b]	Schwetz *et al.*, 1973
	Female	Oral Intubation	Between 0.001 and 0.003	Harris *et al.*, 1973
Rabbits	Mixed	Oral Intubation	0.115	Schwetz *et al.*, 1973
		Skin	0.275	Schwetz *et al.*, 1973
		Intraperitoneal	c	Schwetz *et al.*, 1973
Dogs (beagles)	Male	Oral Intubation	Between 0.3 and 3	Schwetz *et al.*, 1973
	Female	Oral Intubation	Over 0.100	Schwetz *et al.*, 1973

[a] Sporadic deaths with 0.001 to 0.130 mg/kg, without definite dose-response relationship.

[b] In the first study, the animals were given various volumes of vehicle (corn oil-acetone) containing a fixed concentration of TCDD; in the second, they were given a fixed volume of the vehicle containing different TCDD concentrations.

[c] Two to 3 out of 5 animals dying after 0.063 to 0.500 mg/kg.

12 percent mortality, respectively, during the same period. The duration of exposure was less important than the TCDD concentration, and smaller fish were more sensitive than larger ones. The latter was also observed in guppies. When rainbow trout were kept in 5-gallon aquaria with flowing water and TCDD was mixed with the food, 0.0000063 mg per 18 liters (4.75 gallons) of water per week for 4 weeks caused no effect, but a one thousand times greater rate resulted in weight loss and mortality. TCDD at 0.0002 ppm in the water had no effect on pupation of mosquito larvae but reduced reproduction in a pulmonate snail.

All considered, however, there is no doubt that TCDD is a very toxic material indeed. On the toxicity scale in Table II C-6 it would undoubtedly fall under the highest rating (#6). The toxic effect of TCDD in all organisms so far tested is characteristically slow. At LD_{50}, the time to death in male rats was 9 to 27 days, female rats 13 to 43 days, guinea pigs (male and female) between 5 and 42 days, rabbits (male and female) 6 and 39 days, dogs (male) 9 and 15 days (Schwetz et al., 1973). Death in salmon and trout also set in many days after the beginning of treatment (Miller et al., 1973).

The clinical signs of TCDD poisoning are quite diverse. Edema in the chicken has been mentioned before. Other effects include necrotic changes of the liver; gastric hyperplasia and ulceration; hemorrhages in the gastointestinal tract and various other organs; atrophy of the kidneys; and atrophy of the thymus and other lymphoid organs and tissues. The latter changes appear to be the most commonly observed ones and may lead to reduced immunoresponses and thus a decrease in the animal's chemical defense mechanism. But whether any of the above changes are related to the primary toxic action of TCDD is not clear.

The most extensive study on tissue distribution and excretion of TCDD in an animal to date is that of Piper et al. (1973) in rats. The animals were fed a single oral dose of 0.050 mg/kg of TCDD labelled with radioactive carbon (^{14}C). The time for disappearance of half of the ^{14}C from the body ("half-life") was calculated to be 17.4 ± 5.6 days. By day 21, 53.2 percent had been eliminated from the body via the feces, 13.2 percent in urine, and 3.2 percent in expired air. The concentration (as ^{14}C activity) was about ten times greater in the liver and fat than in any other tissue or organ (muscle, bone, skin, heart, lungs, stomach, etc.), but the clearance from those two tissues was relatively faster than from the whole body. The data suggest that TCDD can be retained in the body for periods sufficient to cause subsequent toxicity symptoms and death, and is accumulated in liver and fat. It must, however, be borne in mind that the administered single dose was twice the LD_{50} dose and the physical condition of the animals became quite poor during the experiment. Thus, any conclusions must be tentative.

(5) Teratology

In 1969 it was announced that the isopropyl, butyl, and isooctyl esters of 2,4-D and 2,4,5-T were teratogenic in mice and rats (Mrak, 1969). This raised questions about whether these compounds might also be teratogenic in man. These queries were augmented by the discovery that commercial preparations of 2,4,5-T contained a highly toxic byproduct, TCDD (see preceding section) which itself was teratogenic at very low doses in experimental animals. For this reason we have considered the question of teratogenicity of herbicides separately from other expressions of toxicity.

Before consideration of the possible effects in man, we will briefly discuss the significance of the animal findings.

(a) Some Principles of Teratogenicity

Prenatal development is divided into the embroyonic stage (early) when the organs are forming, and the fetal stage (later) when the organism is maturing during gestation. However, the division is not clear-cut and the prenatal organism will be referred to in this discussion as an embryo even if it is technically known as a fetus.

An agent or chemical is considered as teratogenic when it causes developmental disturbances in the embryo resulting in congenital malformations. If an agent kills the embryo it is said to be embryocidal, and if it produces tissue damage (not necessarily resulting in malformation) it is embryopathic. The term embryotoxic will refer to any harmful effect on the embryo.

The harmful effects of biochemically active compounds vary with the dose of the compound, the route by which it is given, the gestational stage at which the embryo is exposed, and the genetic constitution of the exposed mother and embryo (for further discussion, see Fraser, 1964).

In general, the embryo is more sensitive than the mother, and teratogenic doses are likely to be lower than embryopathic doses which, in turn, are lower than embryocidal doses. However, there is a good deal of overlap, and much variation in this respect between different compounds. For instance, thalidomide is teratogenic in pregnant women at low doses but is not toxic to the mother at very high doses. For many other agents a teratogenic dose also increases the resorption (embryonic mortality) rate, but this is not always so. Still other agents may not be teratogenic even at doses that kill many of the embryos, at least in some species. Finally, the teratogenic effect may vary with the route of administration. Vitamin A, for instance, may be teratogenic when given orally, but is not when given intramuscularly. In general, acute doses are more teratogenic than chronic exposures, possibly because repeated exposure allows the formation (induction) of enzymes which degrade the potentially teratogenic compound.

It is important to recognize that species differ widely in their susceptibility to teratogens. An outstanding example is thalidomide which is highly teratogenic in man and the New Zealand grey rabbit, but has only a very low level of teratogenicity in the mouse and rat. Cortisone causes cleft palate in the mouse and the rabbit, but not in the rat. We still do not know if it is teratogenic in man. Thus, one cannot extrapolate with any assurance from one species to another, or even one strain to another, and one cannot rigorously prove an agent is teratogenic in man from data on experimental animals--only from data on human beings.

It must be emphasized that a great many agents are teratogenic in experimental animals, particularly rodents. Many drugs have demonstrated teratogenicity: various antibiotics, amphetamines, antihistamines, anticonvulsants, barbiturates, caffeine, clomiphene, cyclizine, LSD, thalidomide, tolbutamide, and various tranquilizers. Metals (cadmium, calcium, lead, mercury), hormones (ACTH, adrenalin, androgenic hormones, antiovulatory compounds, estrogens, glucosteroids, insulin, serotonin), vitamin A, and several other kinds of chemical, physiological, and environmental agents (maternal dehydration, maternal stress, carbon monoxide, noise, and hypoxia) have also been shown to be teratogenic in laboratory animals. For several of these there is good evidence of low or no teratogenicity in man (e.g., cyclizine), but for most of them the possibility of low levels of teratogenicity has not been ruled out, and it would be very difficult to do so. Only five have been clearly implicated as human teratogens (diphenylhydantoin, androgenic progestins, organic mercury, radiation, and thalidomide). Experimental 2,4,5-T teratogenicity in rodents must be viewed in this context.

(b) Experimental Work on Teratogenicity of 2,4,5-T, 2,4-D and Picloram

It is clear today that some early results on teratogenicity were due to the presence of 2,4,5-T samples containing TCDD (see next section). However, preparations of 2,4,5-T containing TCDD below the detection limit of 0.05 and 0.02 ppm caused malformations in several experiments with mice (Courtney and Moore, 1971; Roll, 1971; Neubert and Dillmann, 1972). The main abnormality was cleft palate. Courtney and Moore (1971) also observed kidney anomalies, at least in some strains and with some of the 2,4,5-T samples used. The frequency of cleft palate in the offspring of mice treated on day 6 through 15 of pregnancy increased significantly beginning with daily doses of 30 to 100 mg/kg. A butyl ester of 2,4,5-T had a similar effect as the free acid. Neubert and Dillmann (1972) obtained a significant increase also with a single dose of 150 to 300 mg/kg of 2,4,5-T when given on day 12 or 13. Fetal weight was at least in some strains and with some preparations reduced by lower doses than those needed to increase cleft palate but embryo mortality was found only with the latter doses or higher ones.

In other animals, the results on teratogenicity of 2,4,5-T are a good deal less clear-cut. Collins and Williams (1971) treated Golden Syrian hamsters (on day 6 through 10 of pregnancy) with 2,4,5-T preparations varying in TCDD content. They found, in general, an increase in the frequency of abnormalities in the fetuses with increasing TCDD content; this aspect of their work will be discussed later. Out of four 2,4,5-T samples with less than 0.5 ppm TCDD, two caused a statistically significant increase of fetal malformations at 100 mg/kg/day (the highest doses used); the other two did not. A majority of the cases consisted of delayed head ossification which need not result in permanent malformation. Embryo mortality was increased by all four preparations, and where tested, already at doses of 40 or 80 mg/kg. In the rat, Courtney and Moore (1971) and Khera and McKinley (1972), working with several samples of 2,4,5-T and the latter with the butyl ester, found that doses of at least 80 to 100 mg/kg/day on days 6 to 15 of pregnancy caused an increase of frequency of abnormalities also found in the controls or a low frequency of malformations not observed in the latter. Neither cleft palate nor visceral anomalies were observed. The effective doses are quite high; 150 mg/kg/day and above resulted in maternal toxicity while fetal mortality was increased by 100 mg/kg and above. The development of the surviving offspring including behavior was however normal, that is, was not affected by the embryonic defects. Courtney and Moore (1971) concluded that 2,4,5-T was not teratogenic at least in the strain of rats they used. Williams (unpublished) found fetal abnormalities after a single dose of 200 to 400 mg/kg of 2,4,5-T administered on day 9 of pregnancy. Emerson et al. (1971) and Sparschu et al. (1971b) found no malformations in the rat after treatment with 2,4,5-T. These differences probably represent differences in strain susceptibility.

No teratogenicity was produced in rabbits by doses of up to 40 mg/kg/day of 2,4,5-T on days 6 through 18 of pregnancy (Emerson et al., 1971) or 100 mg/kg/day in sheep (Johnson, 1971). In rhesus monkeys, up to 40 mg/kg three times a week between days 20 and 48 also caused no teratogenic effects (Dougherty et al., 1973).

Much less work has been done on the teratogenicity of 2,4-D. One study (Bionetics Study, see Mrak Report, 1969) suggested that the butyl, isopropyl and isooctyl esters of 2,4-D may be teratogens of low potency. Schwetz et al. (1971), feeding the free acid, the propylene, glycol butyl ether ester and the isooctyl ester at levels up to 87.5 mg/kg/day--the maximum tolerated level--on day 6-15 of pregnancy, found symptoms of embryotoxicity (edema, delayed ossification, etc.) but no genuine teratological effects in rats even at the highest dose. The highest levels of the esters decreased viability and lactation in the mothers but had no effect on the growth and development of the offspring. Khera and McKinley (1972), working also with rats and using four samples of 2,4-D and one each of the butyl, isooctyl, butoxyethanol, and dimethylamine derivatives, found similar abnormalities as in their experiments with 2,4,5-T and derivatives, at the same dose levels (100 mg/kg and above). Collins and Williams (1971) found in the progeny of hamsters treated with three samples of 2,4-D some increase in malformations but there was no dose-effect relationship and the differences were not statistically significant.

Only one study on potential embryotoxicity of picloram is available (Thompson et al., 1972). There were no effects on reproduction indices in rats and no signs of embryotoxicity at doses of 500 mg/kg/day, and there were no teratological effects at 750 and 1000 mg/kg/day, levels causing some maternal deaths and retarded fetal development. No reports on teratological studies with cacodylic acid were found in our search of the literature.

(c) Embrytoxic Effects (Embryopathy, Teratogenenicity) of TCDD

TCDD doses that cause relatively little or no effect in adult animals may be markedly toxic to the fetuses (embryos), resulting in reduced litter size due to resorption of fetuses, reduced weight of the fetuses, stillbirths, and pathological symptoms in the fetuses, particularly edema and hemorrhages. Such embryopathic effects have been observed in all species investigated (mainly mice, rats, hamsters). They show that fetuses are more sensitive than adults; this situation is common to many toxic materials.

Teratogenicity of TCDD has been clearly demonstrated in mice. A discussion, based on a review of literature and extensive new experiments, has recently been given by Neubert et al. (1973). The main results and conclusions are:

(1) TCDD causes terata in sensitive strains of mice at levels as low as 0.005 mg/kg when given as a single dose, or 0.001 to 0.002 mg/kg when given daily on days 6 to 15 of pregnancy. Using a suitable form and schedule of administration, teratogenic effects can be produced with great predictability. The main malformation was cleft palate; in addition, some kidney anomalies were observed. TCDD appears to be a highly specific teratogen in mice as no limb malformations were found, even though the treament times included the period of limb formation in the embryo.

(2) As with other teratogens, the teratogenic effectiveness of TCDD is highly dependent on time of administration. In a particular mouse strain, it was greatest on day 11 of gestation. When administered on day 10 or 12, the effect of the same dose was only one-half of that on day 11.

(3) Also, as with many other teratogens, considerable variation in sensitivity towards teratogenesis by TCDD exists between different strains of an animal species. Among the four mouse strains studied, the most and least sensitive ones differed in this respect by a factor of about five.

(4) TCDD is also highly embryopathic in mice. However, again as with many other teratogens, it is possible to obtain a teratogenic effect at non-embryopathic doses. Thus, when TCDD was given to mice daily on days 6 to 15 of pregnancy, a 50 percent effect was caused (i.e., half the progeny exhibited the particular response) by the following doses:

kidney anomalies	0.001-0.003 mg/kg
cleft palate	0.006 mg/kg
death	0.007 mg/kg.

But when the treatment was limited to days 9 to 13 of pregnancy, cleft palate was obtained in high frequency without any apparent mortality of the fetuses. It should be noted that these doses are in the toxic range for non-pregnant adult rats fed weekly doses for 6 weeks (Schwetz et al., 1973; see above).

An interesting result of Neubert et al. (1973) in mice is that when combined with other teratogens or substances suspected of teratogenicity, including 2,4,5-T, at "threshold" or "sub-threshold" doses the incidence of terata may exceed the sum of that caused by each agent alone, that is, there can be potentiation. However, in the case of 2,4,5-T, Neubert et al. calculated that such a potentiation will occur only if the TCDD content of the herbicide exceeds about 3.3 ppm.

A finding that could have far-reaching importance has been recently reported by Moore et al. (1973). Mice were given a single dose of 0.001 mg/kg TCDD on day 10 of pregnancy; their pups were fostered either by mothers who had received the same TCDD treatment, or by untreated mothers. Conversely, pups from untreated mice were allowed to nurse either on untreated mothers, or on mothers which had received 0.001 mg/kg TCDD on day 10 of pregnancy. Pups from untreated mothers nursed by treated ones showed an increased frequency of kidney anomalies (hydronephrosis)[a]. Increased hydronephrosis was also found among the pups of mice which were given one dose of 0.010, 0.003 or 0.001 mg/kg TCDD on the day of parturition. No significant differences in number of live fetuses, resorptions, and fetal and maternal weight were found in the cross-feeding experiments, as compared to the control (pups from untreated mothers nursed by untreated mice), and the authors conclude that the pups had been exposed to TCDD in the milk. The true test that a compound is present in milk is, of course, chemical identification, and it cannot be ruled out that, although the treated mothers did not exhibit weight losses, the quantity and/or quality of their milk was affected. Khera and Ruddick (1973) did not obtain similar results in rats. Pups from mothers treated with 0.001 mg/kg TCDD during days 6 to 15 of gestation, when transferred to non-treated mothers, exhibited high mortality (36 out of 42); pups from non-treated mothers nursed by treated ones did not (two out of 46).

Evidence for teratogenicity of TCDD in animals other than mice is more equivocal. Courtney et al. (1970) reported abnormalities in fetuses of rats which had been treated with 2,4,5-T during pregancy. However, the 2,4,5-T sample used contained 30 ppm TCDD, and in a follow-up study Courtney and Moore (1971) found no teratogenesis in rats treated with 2,4,5-T containing 0.5 ppm TCDD, but did find some hemorrhages in the gastrointestinal tract and some kidney anomalies in fetuses of rats treated with 0.0005 mg/kg/day TCDD (the only dose used). Similar experiments were conducted by Sparschu et al. (1971a) and Khera and Ruddick

[a] A dilation of the kidney due to blockage somewhere in the urinary tract.

(1973), using TCDD doses between 0.0003 and 0.002 mg/kg/day (with higher doses, there were no live fetuses). The incidence of hemorrhages and of subcutaneous edema in fetuses from treated mothers was found to increase with the TCDD dose; Sparschu et al. also found two cases of tail and limb malformations, one each in the 0.00125 and the 0.002 mg/kg/day group. Kidney abnormalities (reported only by Sparschu et al.) and delayed ossification occurred throughout the various groups, including the controls. Working with the Golden Syrian hamster and using 2,4,5-T samples with different TCDD contents, from 45 ppm to nondetectable (presumably, <0.05 ppm), Collins and Williams (1971) found in general an increase in abnormalities per live litter with increasing TCDD content. Most abnormalities were either hemorrhages, or related to fetal head development, namely, delayed ossification and absence of eyelid. Two cases of cleft palate were also observed, but not in the treatments with the highest dioxin levels.

Hemorrhages, edema and delayed ossification are generally considered as embryotoxic responses and not as terata unless it is proven that they result in persistent defects. In the above experiments with rats and hamsters, such proof was not supplied as the offspring were not observed after birth and to maturity. The incidence of unquestionable terata was small and showed no clear dose relationship. On the other hand, almost all treatments were carried out on day 6 through day 15 of pregnancy, and as Neubert et al. (1973) have shown in mice, a different schedule may reduce embryomortality and permit greater expression of teratogenicity (see above). Thus, more experimentation is needed, as is experimentation with animals like non-human primates and pigs which in terms of pathological responses permit somewhat better (although by no means unrestricted) comparisons with humans than do rodents.

(d) Concluding Remarks

An agent may be considered a potent teratogen if it has teratological levels far below the dose levels that are lethally toxic to the mother. By this criterion 2,4,5-T, 2,4-D and also TCDD what we considered as rather weak teratogens in experimental animals. In view of wide differences between species in teratogenic susceptibility, one cannot extrapolate teratological results from experimental animals to man. The best available, though not infallible, indicator of possible human susceptibility are non-human primates. Twelve rhesus (Macaca mulatta) monkeys were dosed three times each week in days 20 to 48 of gestation with 5, 10, 20, and 40 mg/kg of 2,4,5-T containing 0.5 ppm of TCDD. Of the four pregnancies for each of the three lower doses, fetuses developed normally. Two of the four pregnant females treated with the highest dose yielded normal fetuses and the other two had not been hysterotomized at the time of the report (Wilson, 1971). Pregnant rhesus monkeys which were given 2,4,5-T administered in gelatin capsules showed no teratogenic effects nor any gross developmental abnormalities. Monkeys in days 22 to 38 of pregnancy were fed at doses of 0.05, 1.0, and 10.0 mg/kg 2,4,5-T which contained less than 0.05 ppm of TCDD.

Detailed examination of the live infants and stillborn fetus, including skeletal x-ray studies, showed no gross developmental abnormalities in any of the groups (Dougherty et al., 1973). In the latter study, the TCDD content of the 2,4,5-T used was less than 0.05 ppm. Further tests on non-human primates are needed to establish in what order of magnitude the embryopathic dose may be.

A so-called dominant lethal test in rats (Khera and Ruddick, 1973) provided no evidence that TCDD caused the kind of mutations (mostly, chromosome deficiencies) which are detected by this test.

There are reports that TCDD is a mitotic poison in certain plants (Jackson, 1972) and is mutagenic in bacteria (Hussain et al., 1972). While this finding applies also to many other chemicals to which man is exposed, and its significance to higher organisms remains to be established, further studies are indicated to determine whether TCDD presents a genetic as well as teratogenic hazard to man.

(6) Summary and Conclusions

(a) Picloram

Picloram, a component of Agent White, is a selective herbicide highly active on many broad-leaved plants. In the form used in herbicide operations in SVN it has a low volatility, making damage by vapor unlikely, but has a high solubility in water and a high stability in soil which may result in problems of herbicide movement in surface and drainage waters.

The acute oral toxicity of picloram and its salts and esters is low for mammals, and chronic toxicity is low for mammals and a variety of other animals including birds, fish, and crustaceans. No toxicity studies in man are known. No teratogenicity was found in rats at 1000 mg/kg/day.

(b) Cacodylic Acid

Cacodylic acid, the active component in Agent Blue, is a non-selective herbicide killing a wide variety of herbaceous plants. It is a non-volatile, highly soluble organic arsenic compound which is broken down in soil, mostly to inorganic arsenate bound as insoluble compounds which also exist naturally in the soil.

Acute and chronic toxicity studies in a variety of animals indicate a low-to-medium toxicity rating. No teratological studies nor toxicity studies in man seem to have been reported.

(c) 2,4-D and 2,4,5-T

2,4-D and 2,4,5-T as the butyl esters, the active constituents of Agent Orange, are moderately volatile and highly insoluble in water; the triisopropanolamine salt of 2,4-D, present in Agent White, is non-volatile and very soluble in water. Both 2,4-D and 2,4,5-T are stable at ambient temperatures. They are not very persistent within the plant being bound into non-toxic complexes or degraded. A highly toxic compound, TCDD, is found as a contaminant of 2,4,5-T but not of 2,4-D (nor picloram).

Persistence of 2,4-D and 2,4,5-T in the soil is limited, breakdown being largely by microorganisms. Adverse effects on soil microorganisms are found at concentrations of 100 ppm or more, about four times higher than would have been caused by one Agent Orange mission in SVN.

Extensive toxicological studies have shown 2,4,5-T and 2,4-D to be moderately toxic but are still inadequate to define the pharmacology or mechanisms of pathology. In acute exposures, the LD_{50} ranges from 100 (pigs) to 2000 (chicks) mg/kg. Chronic doses are better tolerated and there is little cumulative action--e.g., 100 mg/kg/day for a year caused only minor deleterious effects in cattle, sheep, and chickens. A variety of more or less unsatisfactory observations suggest that these findings apply also to man (if effects caused by TCDD are excluded). Acute exposures such as drenching by sprays sometimes produced vomiting, headache, reduced sensory perception, and limb paralysis. Long-term occupational exposure did not produce any consistent signs of toxicity.

2,4,5-T is moderately teratogenic in mice; cleft palates were produced in the offspring of mice treated with 300-100 mg/kg/day through day 6-15 of pregnancy or a single dose of 150-300 mg/kg on day 12 or 13. Kidney anomalies occurred in some strains. Less clear-cut results were obtained in the hamster and in the rat. No malformations were produced by similar chronic treatments in some rat strains and in rabbits, sheep, and rhesus monkeys. The significance of these findings for man, if any, has not been established.

(d) TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin)

TCDD, a contaminant of 2,4,5-T and thus of Agent Orange, is a very toxic material. Its teratogenicity in mice is well established, though in rhesus monkeys no teratological effects have been found so far. The toxicity to adults of different animal species varies within wide limits (over 1000-fold), and teratogenicity in mice also varies considerably between strains. The teratogenic dose can be lower than the embryolethal dose which, in turn, is somewhat lower than the adult toxic dose. Presence of TCDD in 2,4,5-trichlorophenol and 2,4,5-T was responsible for chloracne outbreaks and some other toxic effects in workers involved in the manufacture of those products.

The presence of TCDD in 2,4,5-T has caused great public concern and TCDD may indeed be the chlorodibenzodioxin that could pose the greatest environmental hazard. It is a stable and persistent compound, but it seems to be taken up by plants to only a very limited extent, and not to be transported from early to later formed parts. Because of this inability for transport in plants, and because of its low solubility, relatively long persistence, and lack of vertical mobility in soils, TCDD more nearly resembles the chlorinated hydrocarbon insecticides in behavior than it does the more biodegradable phenoxy acid herbicides such as 2,4-D and 2,4,5-T, and even picloram. It can be concentrated by aquatic organisms in experimentally designed ecosystems, but to a lesser degree than DDT. Contamination of underground water supplies appears very unlikely.

2,4,5-T is probably the main source of TCDD in the environment. It should, however, be realized that at the present level of <0.05 ppm TCDD in the about 5,000,000 lb of 2,4,5-T presently manufactured annually in the U.S. the amount of TCDD thus produced is maximally about 4 oz. (110 g) per year which are spread over several millions of acres. 2,4,5-trichlorophenol should not be entirely disregarded as another potential source of TCDD. A closely related compound, hexachlorodibenzo-para-dioxin, toxic at levels about 10 to 30 times higher than TCDD, may be present in, or produced from a widely used chemical, pentachlorophenol. All herbicides used in the herbicide operations in SVN are toxic to animals, in varying degrees. Some of them have been found to cause death, tissue damage, or malformations in embryos of exposed pregnant female animals. TCDD is highly toxic and is teratogenic at least in mice. Although these entire findings cannot be extrapolated to man, the question of possible harm to human embryos is raised. Further intensive studies are especially required with reference to the ecological distribution, the pharmacology, mechanism of toxicity, possible mutagenicity, and carcinogenicity of TCDD and its possible teratogenicity in man.

REFERENCES

Akamine, E.K., 1951. Persistence of 2,4-D toxicity in Hawaii soils. Bot. Gaz. 112:312-319.

Alabaster, J.S., 1969. Survival of fish in 164 herbicides, insecticides, fungicides, wetting agents and miscellaneous substances. Int. Pest. Control 11(2):29-35.

Allen, J.R. and L.A. Carstens, 1967. Light and detection microscopic observations in Macaca mulatta monkeys fed toxic fat. Am. Jour. Vet. Res. 28:1513-1526

Audus, L.J., 1970. The action of herbicides and pesticides on the microflora. Mededelingen Faculteit Landbouwwetenschappen Gent 35(2):465-492.

Bauer, J.R., R.W. Bovey and J.D. Smith, 1969. Herbicide concentrations in live oak treated with mixtures of picloram and 2,4,5-T. Weed Science 17:567-570.

Baughman, Robert and Matthew Meselson, personal communication to Dr. Anton Lang, 1973.

______, 1973a. An improved analysis for tetrachlorodibenzo-p-dioxin. Advances in Chemistry Series 120:92-104.

______, 1973b. An analytical method for detecting TCDD (Dioxin): Levels of TCDD in samples from Vietnam. Environmental Health Perspectives, Experimental Issue No. 5, 27-36.

Björklund, Nils-Erik and Kurt Erne, 1971. Phenoxy-acid-induced renal changes in the chicken. I. Ultra-structure. Acta Vet. Scand. 12:243-256.

Bohmont, B.L., 1967. Toxicity of herbicides to livestock, fish, honeybees, and wildlife. 20th Western Weed Control Conf. Proc. 21:25-27.

Bureau of Sport Fisheries and Wildlife, U.S. Dept. of Interior, 1962. Effects of pesticides on fish and wildlife: A review of investigations during 1960. Circular 143, Washington, D.C.

Bureau of Sport Fisheries and Wildlife, U.S. Dept. of Interior, 1963. Pesticide wildlife studies: A review of fish and wildlife service investigations during 1961 and 1962. Circular 167, Washington, D.C.

Bureau of Sport Fisheries and Wildlife, U.S. Dept. of Interior, 1964. Pesticide wildlife studies 1963: A review of fish and wildlife service investigations during the calendar year. Circular 199, Washington, D.C.

Buu-Hoi, N.P., G. Saint-Ruff, P. Bigot, M. Mangane, 1971. Preparation properties and identification of "dioxin" in pyrolystates of defoliants containing 2,4,5-trichlorophenoxyacetic acid, their esters, and contaminated plants. C.R. Acad. Sci., Paris, Ser. D, 273(7):701-711. (In French).

Chow, C., M.L. Montgomery and T.C. Yu, 1971. Methodology and analysis for residues of MPC and 2,4,5-T in wheat. Bull. Environm. Contam. Toxicol. 6:576-580.

Clark, D.E. and J.S. Palmer, 1971. Residual aspects of 2,4,5-T and an ester in sheep and cattle with observations on concomitant toxicological effects. Jour. Agric. Food Chem. 19:761-764.

Clark, D.E., H.R. Crookshank, R.D. Radeleff, J.S. Palmer and W. Binns, 1971. Chlorophenoxy acid residues in sheep and cattle. Paper read at 162nd Natl. Meet. Amer. Chem. Soc., September 12-17, Washington, D.C.

Coakley, J.E., J.E. Campbell and E.F. McJarren, 1964. Determination of butoxyethanol ester of 2,4-D acid in shellfish and fish. Jour. Agric. Food Chem. 12:262-265.

Collins, T.F.X., and C.H. Williams, 1971. Teratogenic studies with 2,4,5-T and 2,4-D in the hamster. Bull. Environ. Contam. & Toxicol. 6(6):559-567.

Cope, O.B., E.M. Wood and G.H. Wallen, 1970. Some chronic effects of 2,4-D on the bluegill (Lepomis machrochirus). Transact. Amer. Fish. Soc. 99:1-12.

Courtney, K.D., D.W. Gaylor, M.D. Hogan, H.L. Falk, R.R. Bates, and I. Mitchell, 1970. Teratogenic evaluation of 2,4,5-T. Science 168:864-866.

Courtney, K.D. and J.A. Moore, 1971. Teratology studies with 2,4,5-trichlorophenoxyacetic acid and 2,3,7,8-tetrachlorodibenzo-p-dioxin. Toxicol. & Appl. Pharmacol. 20(3):396-403.

Crosby, D.G., K.W. Moilanen and A.S. Wong, 1973. Environmental generation and degradation of dibenzodioxins and dibenzofurans. Environmental Health Perspectives, Experimental Issue, No. 5, 259-266.

Crosby, D.G., and A.S. Wong, 1973. Photochemical generation of chlorinated dioxins. Science, in preparation.

Devine, J.M., 1970. 2,4,5-T residues in rough rice and rice straw. Syracuse University Report SURC-2, 200-207.

Dougherty, W.H., F. Coulston, and L. Goldberg, 1973. Non-teratogenicity of 2,4,5-trichlorophenoxyacetic acid in monkeys (Macaca mulatta). Abstract of paper presented at 12th Annual Meeting of Society of Toxicology held March 18-22, 1973 in New York, N.Y.

Drill, V.A. and T. Hiratzka, 1953. Toxicity of 2,4-dichlorophenoxyacetic acid and 2,4,5-trichlorophenoxyacetic acid. Arch. Industr. Hyg.

Dubey, H.D., 1969. Effect of picloram, dioxin, ametryne and promethyne on nitrification in some tropical soils. Proc. Soil Sc., Soc. Amer., 33:893-896.

Ebbersten, S., 1972. Pikloram (4-amino-3,5,6-triklorpikolinsyra). Institutionen for vaxtodling, Lantbrukshogskolan, Uppsala, Sweden.

Emerson, J.L., D.J. Thompson, R.J. Strebing, C.G. Gerbig and V.B. Robinson, 1971. Teratogenic studies of 2,4,5-T in the rat and rabbit. Food Cosmet. Toxicol. 9:395-404.

Erne, K., 1966. Distribution and elimination of chlorinated phenoxyacetic acids in animals. Acta Vet. Scand. 7:240-256.

______, 1971. Fexoxisyror och vilt. Statens Veterinarmedicinska Anstalt, Stockholm.

______, 1972. Toxikologisa risker med fenoxisyror - några nyare resultat. Ogras och Ograsbekampning, 13:e Svenska Ograskonferensen, Uppsala, Sweden.

Fetisov, M.I., 1966. Occupational hygiene in work with herbicides of the 2,4-D group. Gigiena Sanit. 31:28-30. (In Russian.)

Finnish Board of Medicine, 1973. Working group for the study of the impact of herbicides on human health. Report. Helsinki. (In Finnish.)

Firestone, David, J. Ress, N.L. Brown, R.P. Barron and J.N. Damico, 1972. Determination of polychlorodibenzo-p-dioxins, and related compounds in commercial chlorophenols Jour. Assoc. Official Anal. Chemists 55(1):85-92.

Fletcher, U.U., 1966. Herbicides and the bio-activity of the soil. Landbouwk. Tijdschra, 78:274-281.

Frasor, F.C., 1964. Experimental teratogenesis in relation to congenital malformations in man. Proc. Second International Congress of Congenital Malformations, International Medical Congress, Ltd., N.Y.

Fullerton, P.M., 1969. Toxic chemicals and peripheral neuropathy.
Proc. Roy. Soc. Med. 62:201-204.

Gehring, P.J., C.G. Kramer, B.A. Schwetz, J.Q. Rose, V.K. Rowe and J.S. Zimmer, 1973. The fate of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) following oral administration to man.
Toxicol. and Appl. Pharmacol. 26, in press.

Getzendaner, M.E., 1958. 2,4-D in asparagus.
The Dow Chemical Company, Report GH-C 224.

______, 1965. A study of residues of 2,4-D in peanuts, immature vines and hay after field applications.
The Dow Chemical Company, Report GH-C 150.

______, 1973. Fate of herbicides in forage crops.
Joint Session Agronomy, Animal Science and Dairy Science, Southern Agricultural Workers, Symposium: Guidelines for Wholesome Food Production (6 February 1973).

Gleason, N., R.E. Gosselin, H.C. Hodge and R.P. Smith, 1969. Clinical toxicology of commercial products: acute poisoning.
Williams & Wilkins, Baltimore.

Goring, C.A.I., J.D. Griffith, F.C. O'Meila, H.H. Scott and C.R. Youngson, 1967. The effect of Tordon on micro-organisms and soil biological processes.
Down to Earth 22:14-17.

Hamaker, J.W. and H.O. Kerlinger, 1969. Vapor pressure of pesticides.
Advances in Chemistry Series, No. 86:39-54.

Hansen, W.N., et al., 1971. Chronic toxicity of 2,4-dichlorophenoxy-acetic acid in rats and dogs.
Toxicol. Appl. Pharmacol.

Harris, M.W., J.A. Moore, J.G. Vos, and B.N. Gupta, 1973. General biological effects of TCDD in laboratory animals.
Environmental Health Perspectives, Experimental Issue, No. 5, 101-110.

Heath, R.G., J.W. Spann, E.F. Hill, and J.F. Freitzer, 1972. Comparative toxicities of pesticides to birds.
Special Scientific Report - Wildlife No. 172. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, U.S. Department of Interior, Washington, D.C.

Hughes, J.S. and J.T. Davis, 1963. Variations in the toxicity to bluegill sunfish of phenoxy herbicides.
Weeds 11:50-53.

______, 1966. Toxicity of pesticides to bluegill and sunfish tested during 1961-66.
Louisiana Wildlife and Fisheries Commission, Monroe, Louisiana.

Hussain, S., L. Ehrenberg, G. Lofroth and T. Gejvall, 1972. Mutagenic effects of TCDD on bacterial systems.
Ambio 1(1).

Isensee, A.R. and G.E. Jones, 1971. Adsorption and translocation of root and foliage applied 2,4-dichlorophenol, 2,7-dichlorodibenzo-p-dioxin, and 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Agric. Food Chem. 19:1210-1214.

Jackson, W.T., 1972. Regulation of Mitosis. III. Cytological effects of 2,4,5-trichlorophenoxyacetic acid and of dioxin contaminants in 2,4,5-T formulations.
Jour. of Cell Science 10:15-25.

Jensen, D.J. and L. Berhenke, 1973. Analysis for "bound" residues in rice grain, straw and hulls from plots treated with 2,4,5-T.
The Dow Chemical Company, Report GH-C 638.

Johnson, J.E., 1971. The public health implications of widespread use of the phenoxy herbicides and picloram.
BioScience 21(17):899-905.

Kearney, P.C., E.A. Woolson, A.R. Isensee and C.S. Helling, 1973. Tetrachlorodibenzodioxin in the environment: sources, fat and decontamination.
Environmental Health Perspectives, Experimental Issue No. 5, 273-278.

Kenaga, E.E., 1969. Tordon herbicides--evaluation of safety to fish and birds.
Down to Earth 25(1):5-9.

Ketchersid, M.L., D.H. Fletchall, P.W. Santleman and M.G. Merkle, 1970. Residues in sorghum treated with the isooctyl ester of 2,4-D.
Pesticide Monitoring Jour. 4:111-113.

Khera, K.S. and W.P. McKinley, 1972. Pre- and post-natal studies on 2,4,5-trichlorophenoxyacetic acid, 2,4-dichlorophenoxyacetic acid and their derivatives in rats.
Toxicol. Appl. Pharmacol. 22:14-28.

Khera, K.S. and J.A. Ruddick, 1973. Polychlorodibenzo-p-dioxins: perinatal effects and the dominant lethal test in Wistar rats.
Advances in Chemistry Series 121:70-84.

Kramer, C.G. and M.G. Ott, Industrial Hygiene and Medical Departments, The Dow Chemical Company (unpublished).

Kutschinski, A.H. and V. Riley, 1969. Residues in various tissues of steers fed 4-amino-3,5,6-trichloropicolinic acid.
Jour. Agric. Food Chem. 17:283-287.

Langer, H.G., T.P. Brady and P.R. Briggs, 1973. Formation of dibenzodioxins and other condensation products from chlorinated phenols and derivatives. Environmental Health Perspectives, Experimental Issue No. 5, 3-8.

Long, K.R., V.B. Beat, A.K. Gombart, R.F. Sheets, H.E. Hamilton, F. Falaballa, D.P. Bonderman and U.Y. Choi, 1969. The epidemiology of pesticides in a rural area.
Jour. Amer. Industr. Hyg. Assoc. 30:298:304.

Lutz, H. and Y. Lutz-Ostertag, 1970. Baneful action of the herbicide 2,4-D on the embryonic development and the fertility of game birds.
C.R. Acad. Sci., Paris, Ser. D, 271:2418-2421.

Matsumura, F., and H.J. Benezet, 1973. Studies on the bioaccumulation and microbial degradation of 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Environmental Health Perspectives, Experimental Issue No. 5, 253-258.

McCollister, D.D. and M.L. Leng, 1969. Toxicology of picloram and safety evaluation of Tordon herbicides.
Down to Earth 25:5-10.

Miller, R.A., L.A. Norris and C.L. Hawkes, 1973. Toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in aquatic organisms.
Environmental Health Perspectives, Experimental Issue No. 5, 177-186.

Moore, J.A., B.N. Gupta, J.G. Zinkl, and J.G. Vox, 1973. Postnatal effects of maternal exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).
Environmental Health Perspectives, Experimental Issue No. 5, 81-86.

Mrak, E.M., chairman, 1969. Report of the Secretary's Commission on pesticides and their relationship to environmental health.
Dept. of Health, Education and Welfare, Government Printing Office, Washington, D.C.

Neubert, D., and I. Dillmann, 1972. Embryotoxic effects in mice treated with 2,4,5-trichlorophenoxyacetic acid and 2,3,7-8-tetrachlorodibenzo-p-dioxin.
Arch. Pharmacol. 272:243-264.

Neubert, D., P. Zens, A. Rothenwallner and H.J. Merker, 1973. A survey of the embryotoxic effects of TCDD in mammalian species.
Environmental Health Perspectives, Experimental Issue No. 5, 67-80.

Norback, D.H. and J.R. Allen, 1973. Biological responses of the nonhuman primate, chicken, and rat to chlorinated dibenzo-p-dioxin ingestion.
Environmental Health Perspectives, Experimental Issue No. 5, 233-240.

Palmer, J.S. and R.D. Radeleff, 1969. The toxicity of some organic herbicides to cattle, sheep, and chickens.
U.S. Dept. of Agriculture, Agric. Res. Service, Production Research Report 106, Washington, D.C.

Piper, W.N., J.Q. Rose and P.J. Gehring, 1973. Excretion and tissue distribution of 2,3,7,8-tetrachlorodibenzo-p-dioxin in the rat. Environmental Health Perspectives, Experimental Issue No. 5, 241-244.

Piper, W.N., J.Q. Rose, M.L. Leng, and P.J. Gehring, 1973. The fate of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) following oral administration to rats and dogs. Toxicol. Appl. Pharmacol. 26, in press.

Plimmer, J.R., 1973. Technical pentachlorophenol: origin and analysis of base-insoluble contaminants. Environmental Health Perspectives, Experimental Issue No. 5, 41-48.

Plimmer, J.R., et al, 1973. Photochemistry of dibenzo-p-dioxins. Advances in Chemistry Series, 120:44.

Poland, A.P., D. Smith, G. Metter, and P. Possick, 1971. A health survey of workers in a 2,4-D and 2,4,5-T plant. Arch. Environm. Health 22:316-327.

Roll, R., 1971. Untersuchungen uber die teratogene Wirkung von 2,4,5-T bei Mausen (Studies of the teratogenic effect of 2,4,5-T in mice) Food and Cosmetic Toxicology 9(5):671-676. (In German).

Rowe, V.K., and T.A. Hymas, 1954. Summary of toxicological information on 2,4-D and 2,4,5-T type herbicides and an evaluation of the hazards to livestock associated with their use. Amer. Jour. Vet. Res. 15(57):622-629.

Sanders, H.O., 1970(a). Toxicities of some herbicides to six species of freshwater crustaceans. Jour. Water Pollut. Control Fed. 42:1544-1550.

______,1970(b). Pesticides toxicities to tadpoles of the Western Chorus Frog *Pseudacris triseriata* and Fowler's Toad *Bufo woodhousii fowleri*. Copeia 2:246-251.

Schroeder, H.A. and J.J. Balassa, 1966. Abnormal trace metals in man. Jour. Chron. Diseases 19:85-106.

Schwetz, B.A., G.L. Sparschu and P.J. Gehring, 1971. The effect of 2,4-dichlorophenoxyacetic acid (2,4-D) and esters of 2,4-D on rat embryonal, foetal and neonatal growth and development. Food & Cosmetics Toxicology 9(6):801-819.

Schwetz, B.A., J.M. Norris, G.L. Sparschu, V.K. Rowe, P.J. Gehring, J.L. Emerson and C.G. Gerbig, 1973. Toxicology of chlorinated dibenzo-p-dioxins. Environmental Health Perspectives, Experimental Issue No.5, 87-100.

Smith, A.E., 1972. The hydrolysis of 2,4-dichlorophenoxyacetate esters to 2,4-dichlorophenoxyacetic acid in Saskatchewan soils. Weed Res. 12:364-372.

Somers, J.D., 1972. Influence of external applications of pesticides on egg hatchability and chick viability. M.S. Thesis, University of Guelph, Guelph, Ontario, Canada.

Sparschu, G.L., F.L. Dunn and V.K. Rowe, 1971(a). Study of the teratogenicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin in the rat. Food Cosmet. Toxicol. 9:405-412.

Sparschu, G.L., F.L. Dunn, R.W. Lisowe and V.K. Rowe, 1971(b). Study of the effects of high levels of 2,4,5-trichlorophenoxyacetic acid on foetal development in the rat. Food Cosmet. Toxicol. 9:527-530.

Sundell, L., 1972. Herbicides and mortality: an epidemiological investigation of spraying staff employed by the Swedish State Railways (SJ) (In Swedish). (Mimeographed) Clinic of Occupational Medicine, Regional Hospital, Orebro, Sweden.

Thompson, D.J., J.L. Emerson, R.J. Strebing, C.G. Gerbig and V.B. Robinson, 1972. Teratology and postnatal studies on 4-amino-3,5,6-trichloropicolinic acid (picloram) in the rat. Food and Cosmet. Toxicol. 10:797-803.

HQ., U.S. Military Assistance Command, Vietnam (MACV) Directive 525-1, dated 12 August 1969, with four Annexes.

U.S. Tariff Commission. 1967. Synthetic Organic Chemicals: United States Production and Sales, 1967. TC Publn. No. 295, 212 pp. U.S. Government Printing Office, Washington, D.C.

U.S. Tariff Commission. 1970. Synthetic Organic Chemicals: United States Production and Sales, 1970. TC Publn. No. 479, 262 pp. U.S. Government Printing Office, Washington, D.C.

Williams, unpublished.

Wilson, J.G., 1971. Report of the Advisory Committee on 2,4,5-T to the Administrator of the Environmental Protection Agency. Children's Hospital Medical Center, Cincinnati, Ohio.

Woolson, E.A. personal communication.

Woolson, E.A., R.F. Thomas and P.D.J. Ensor, 1972. Survey of polychlorodibenzo-p-dioxin content in selected pesticides. Jour. Agr. Food Chem. 20(2):351-354.

Woolson, E.A., W.L. Reichel, A.L. Young and P.D.J. Ensor, 1973. Dioxin residues in Lakeland sand and bald eagle samples. Advances in Chemistry Series, 120:112-118.

D. Earlier Studies of the Effects of Herbicides in South Vietnam

There have been a number of published studies based on direct observation of effects of the military herbicide spray programs in SVN. Most of these reports have been prepared by U.S. military personnel, or under contract with DOD. Some were written by U.S. scientists from other Federal agencies or from private organizations, two by people from DRVN, and one was prepared by the Government of RVN. The major studies are listed in Table II D-1.

These reports served to lay out principal issues regarding military effectiveness or counter-productivity, persistent ecological damage or its absence, association of herbicide exposure with deleterious effects on human health, or the absence of such association. Some of these reports will be discussed later in the present study.

Table II D-1

Some Reports on Military Herbicide Operations
Based on Field Observations of Effects in SVN

DOD and DOD Contract Studies

a. "Evaluation of Herbicide Operations in the Republic of Vietnam - September 1962-September 1963." MACV Task Force Saigon Herbicide Evaluation Team. October 1963

b. "Evaluation of Herbicide Operations in the Republic of Vietnam." MACV. July 1966

c. "Herbicide Operations in South East Asia - July 1961-June 1967." Contemporary Historical Evaluations of Combat Operations, Headquarters, Pacific Air Force. October 1967

d "A Statistical Analysis of the U.S. Crop Spraying Program in South Vietnam." Rand Corporation. October 1967

e. "An Evaluation of Chemical Crop Destruction in Vietnam." Rand Corporation. October 1967

f. "Assessment of Ecological Effects of Extensive or Repeated Use of Herbicides." Midwest Research Institute. December 1967

g. "Crop Destruction Operations in the Republic of Vietnam During 1967." Commander-in-Chief, Pacific (CINCPAC). December 1967

h. "Report." Herbicide Policy Review Committee, American Embassy Saigon and MACV. Classified version, May 1968; unclassified version, August 1968

i. "Review of the Herbicide Program in South Vietnam." CINCPAC. August 1968

j. "Congenital Malformations, Hydatidiform Moles and Stillbirths in the Republic of Vietnam 1960-1969." Cutting, Robert T., Tran Huu Phuoc, Joseph M. Ballo, Michael W. Benenson, and Charles H. Evans. U.S. Army Medical Research Team, Ministry of Health, Government of Vietnam, and Office of the Command Surgeon, MACV. U.S. Government Printing Office. December 1970

k. "Herbicides and Military Operations." Office, Chief of Engineers, Department of the Army. February 1972

<u>U.S. Department of Agriculture, at request of U.S. Embassy, Saigon</u>

l. "Defoliation in Vietnam." F. H. Tschirley. <u>Science</u> 163:779-786, 21 February 1969

<u>Government of RVN</u>

m. "Defoliation with Chemicals." The Director of Water and Forests. Saigon, March 1971

<u>Other</u>

n. "A Partial Evaluation of Herbicidal Effects to Natural Forest Stands Principally in Tay Ninh Province." B. R. Flamm, Forestry Advisor, USAID/ADDP Vietnam. April 1968

o. "Ecological Effects of the War in Vietnam." G. H. Orians and E. W. Pfeiffer. <u>Science</u> 168:544-554, 1 May 1970

p. "Effects of Herbicides and Defoliants on the Fauna and Flora of South Vietnam (Preliminary Survey)." Duong Hong Dat. Vietnamese Studies No. 29, 1971. Documents of the International Conference of Scientists on U.S. Chemical Warfare in Viet Nam, Paris, December 1970. Hanoi

q. "Clinical Effects of Massive and Continuous Utilization of Defoliants on Civilians (Preliminary Survey)." Ton That Tung et al. (DRVN delegation). Vietnamese Studies No. 29, 1971. Documents of the International Conference of Scientists on U.S. Chemical Warfare in Viet Nam, Paris, December 1970. Hanoi

r. "Preliminary Report." Herbicide Assessment Commission of the American Association for the Advancement of Science. M. S. Meselson; A. H. Westing; J. D. Constable; and R. E. Cook. <u>Congressional Record</u> 118(32):S3226-3233, March 3, 1972.

s. "Forestry and the War in South Vietnam." A. H. Westing. <u>J. Forestry</u> 69:777-783, November 1971

t. "Effects of War Damage on the Forest Resources of South Vietnam." B. R. Flamm and J. H. Craven. <u>J. Forestry</u> 69:784-789, November 1972

E. Brief Survey of South Vietnam

(1) Geography, Climate

South Vietnam occupies 69,715 square miles (174,289 square kilometers) of the southeastern extremity of the mainland of Southeast Asia, extending from 8°33' to 17° north latitude and from 104° to 109° east longitude. The country has four natural physiographic regions: (1) the southernmost area, the Mekong Delta of 14,918 mi^2 (37,296 km^2), (2) the transitional area between the Mekong Delta and the Central Highlands, the Terrace Region of 12,350 mi^2 (30,876 km^2), (3) the Central Highlands of 20,165 mi^2 (50,412 km^2), and (4) the Coastal Lowlands of 22,282 mi^2 (55,705 km^2). (Data from Viet Nam Statistical Yearbook, 1971.)

The Government of the RVN has established 44 provinces and 11 autonomous municipalities. During the U.S. involvement in SVN the country was divided into four major Military Regions (MR I in the north to MR IV in the south) plus the Capital Special Zone and the Rung Sat Special Zone, which occupy part of Gia-Dinh Province.

SVN has a tropical monsoon type climate with a distinct dry and wet season occurring each year. The wet season or the southwest monsoon extends from mid-May to late September and the dry season or northeast monsoon extends from early November to mid-March. For most of the country, the southwest monsoon is the wet season. However, the northeastern coast, which is in the rain shadow of the Truong Son mountain range, experiences a dry season during the southwest monsoon, while the wet season is brought by the northeast monsoon during the months of September through January.

As in most tropical countries, temperatures are high at all times of the year. The average annual temperature varies only a few degrees from north to south; in Hue, near the northern boundary, it is 77°F (25°C), in Saigon it is 80.4°F (26.9°C). The relative humidity is very high (80-90 percent) during the wet season, and much lower during the hot, dry season. Precipitation is relatively heavy in all regions but with definite monsoonal variations, averaging about 90 inches (2250 mm) along the southern coast, 70 inches (1750 mm) over the Mekong Delta, and 77 inches (1925 mm) at Saigon.

(2) Population

The South Vietnamese people numbered approximately 12,935,000 in 1958 and were estimated to have increased to 18,708,000 by 1971. The country as a whole, by Asian standards, is not densely populated--about 260 persons per square mile, but because of the uneven distribution of the inhabitants, local concentrations are high. Population Density Maps for June 1967 and 1971 are included in the Map Section.

Almost 80 percent of the people are ethnically Vietnamese. The Chinese represent the largest minority, with approximately 1.2 million, two-thirds of whom live in the Cholon area of Saigon. The Highlanders or Montagnards, numbering approximately 700,000 to 1,000,000 are composed of over 30 tribes of various cultures and languages and are spread over the the entire Central Highlands and the Terrace Region. The Khmers (Cambodians) number about 400,000 and are located in the inner edge of the Mekong Delta; they occupied the entire Delta prior to the arrival of the Vietnamese. Smaller minority groups include the Chams (the former rulers of the Central Coast), and relatively recent immigrants: Indians, Pakistanis, Europeans, and Americans.

(3) Soils and Vegetation

The wide variations in climate and the greatly diversified geologic parent material in SVN have contributed to the development of many different groups of soil. Table II E-1 shows the Major Soil Associations and their relationship to land-use and vegetation cover as discussed by Moormann (1961).

The Alluvial soils which are found almost entirely in the Mekong Delta Region, are generally fertile, i.e. they contain organic matter and plant nutrients such as potassium, phosphorus, calcium, and magnesium in relatively high quantities and in a form readily accessible ("available") to plants. Exceptions are locations where high acidity and/or high aluminum content are unfavorable for plant growth, as in the Plain of Reeds in the northern part of the Delta. The other soils of SVN, which occur mainly in the hilly and mountainous parts of the country, are--with the exception of some Black Tropical soil--acidic and of low fertility; varying but relatively large parts of the available plant nutrients are tied up in the above-ground parts of the vegetation (see Section V B). A map of the Major Soil Associations (modified from Moormann, 1961) is included in the Map Section.

The vegetation of SVN is rich in species and diversified in types. This diversity is due to the great range of climate, topography, and soil, as well as to the widely varying types and intensity of human impacts. Almost everywhere human activities such as swidden agriculture[a], logging, and

[a] This form of agriculture also is known variously as slash-and-burn, primitive horticulture, field-forest rotation, shifting-field agriculture, and brand tillage, as well as by such local names as ray (the term used in most French and Vietnamese literature on the Highlands of Vietnam). The word swidden for "burned clearing" has been favored in a number of recent works, and it has the dual advantage of being a general designation not linked to any particular region, and that it can be used as a noun.

Table II E-1. Major Soil Association of South Vietnam, Land Use and Vegetation Cover
After F. R. Moormann (1961)

	Soil Unit	Percentage of Soil Distribution in South Vietnam	Typical Location	Land Use and Vegetation Cover
1.	Red and Yellow Podzolic Soils On acid rock, on old alluvium, on mountains.	43	Central highlands	Very little permanent field cultivation; some swidden cultivation. Dense Forests, Pine Forests, Savanna.
2.	Alluvial Soils Undifferentiated, Saline, Acid, Very Acid, Brown	27.5	Mekong Delta	Intensive permanent field cultivation on inland plains; mangrove swamps; rice, coconuts, sugar cane, pineapples. Mangrove forest and Melaleuca woodlands.
3.	Latosols (Red Soils) Reddish Brown, Red, Earthy Red, Shallow, Reddish Brown and Red, Reddish Brown and Compact Brown	12	Central highlands; basaltic plateaus; Xuan-Loc, Dalat, Pleiku	Some permanent field cultivation; little swidden cultivation, rubber, coffee, tea, fruit trees. Dense Forests, Secondary Forests, some Savanna.
4.	Gray Podzolic Soils	9.5	Old terraces of Mekong River system; Pleiku-Darlac basaltic plateaus	Some swidden cultivation; rubber, manioc, peanuts. Dense Forest, Secondary Forests.
5.	Regurs and Latosols	2	Cheo-Reo depression; Phu-Yen, Darlac, and Long Khanh Provinces	Some swidden cultivation; diverse crops, corn, dry rice, manioc, bananas, rubber. Dense Forest, Secondary Forests.
6.	Regosols	2	Central coastal lowlands	Very little permanent field cultivation; some diverse crops, coconuts, manioc, peanuts. Sparse vegetation to dense brush.
7.	Sandy Podzolic Soils	2	Binh-Tuy, Darlac and Pleiku Provinces	Very little swidden cultivation. Secondary Forests.
8.	Non-Calcic Brown Soils	1	Coastal plains of Phan-Rang region	Little permanent field cultivation; some swidden cultivation, tobacco, cotton, rice. Savanna vegetation with dense brush.
9.	Podzolic Soils and Regurs Podzolic Soils and Alluvial Soils	0.4	Cheo-Reo depression; coastal plains; central lowlands	Frequent swidden cultivation; rice; diverse food crops. Secondary Forests.
10.	Peat and Muck Soils	0.6	Mekong Delta, U-Minh	Very little cultivation; some rice, vegetables and fruit. Melaleuca woodlands.

fuel gathering have left their mark on the plant cover, and little undisturbed vegetation can now be found. Bernard Rollet in 1956 prepared a 1:1,000,000 scale vegetation map of SVN based on 1952-53 aerial photographs and in 1962 a "note" (memorandum) on this map. Table II E-2 lists the major vegetation types and their extent in SVN as given in the Rollet "note." A map of the Major Vegetation Types of SVN, simplified from Rollet's map, is included in the Map Section[a].

Some 29,689,400 acres (120,200 km^2) in SVN was classified as forests (Rollet, 1962). Part of the forest is of the dense forest type of Rollet. This forest type is characterized by a canopy through which the ground cannot be seen from above and is therefore called Closed forest. This forest is rich in broad-leaved evergreen and semi-evergreen trees, some of which produce valuable timbers. Of this forest type, 18 percent was classified as dense[b] (relatively undisturbed) forests, when Rollet made his vegetation map. By now, this forest type has decreased further and remains mainly in the more remote parts of the Central Highlands. Elsewhere the dense forest has been replaced by secondary forests of various types which have been drastically affected by centuries of swidden agriculture and in more recent times by logging. Over extensive areas such treatment has led to the replacement of broad-leaved trees by dense thickets of bamboo.

Open forests resulting from burning and other forms of human interference, are found in the western Plateau area of the Central Highlands and in the lower Terrace Region. Pine forests occupy a small area, mainly on the high plateau near Dalat.

Mangrove forests, which are a characteristic feature in the tidal zone on most alluvial coasts and along the salt-water estuaries of streams and rivers in the tropics, form in SVN the vegetative cover on sediments in salt and brackist water. They are developed most extensively from Vung Tau City (southeast of Saigon) southward to the southernmost tip of the country and from there northward along the west coast to the Cambodian border. Particularly large tracts of mangrove are found in two locations: (1) Gia Dinh Province, southeast of Saigon, including the Rung Sat Special Zone and reaching into the southernmost part of Bien Hoa Province and the southwestern part of Phuoc Tuy Province; and (2) in

---

[a] The total area of SVN in Table II E-2 and that given in Section II E(1) differ. They have been taken from the respective sources without change. The reasons for the difference are not evident.

[b] In Southeast Asia, Rollet and others recognize that genuine primary forests have become quite rare and that most dense forests are in fact old secondary forests.

Table II E-2

Major Vegetation Types in SVN
According to Rollet (1962)[a]

Vegetation Type	Rollet's Nomenclature	Approximate Area: Acres (x 1000)	Approximate Area: Square Kilometers	Percentage of Total Land
Closed Forest				
(a) Dense (1)[b]	Forêts denses	7,608	30,800	18.3
(b) Secondary (2)	Forêts secondaires	15,067	61,000	36.3
Open and Semi-Dense Forest	Forêts claires, Forêts semi-dense			
(a) Dipterocarp forests (4)		2,001	8,100	4.8
(b) *Lagerstroemia* and Leguminosae forests (5)		988	4,000	2.4
Pine Forests (8,9)	*Pinus merkusii*, *Pinus khasya*	445	1,800	1.1
Mangrove Forests (13)	Mangrove	716	2,900	1.7
Melaleuca woodlands (19)	*Melaleuca*	469	1,900	1.1
Savanna (6)	Savanes	1,976	8,000	4.8
Barrenlands, high degraded dry forests, sand dunes (7,14,18)	Végétation buissonnante, Forêts sèches du Sud-Est, Dunes	2,001	8,100	4.8
Grasslands and Steppes (10,11,12)	Steppes, pelouses, prairies d'altitude	569	2,300	1.3
Grass and sedge swamps, Plain of Reeds vegetation, rivers (16,17)	Prairies marécageuses, Végétation de la Plaine des Joncs, Fleuves	1,803	7,300	4.4
Cultivated land (15)	Cultures, Rizieres	7,855	31,800	19.0
(a) Rice (irrigated)				
(b) Tree plantations, rubber, coconut, etc.)				
Totals		41,498	168,000	100

[a]The areas reflect the situation in 1952-1953 when the aerial photographs were taken on which Rollet based his vegetation classification.

[b]Figures in parenthesis refer to Rollet's vegetation types from his map of 1956. See Section III A.

the southernmost tip of the country, the Ca Mau Peninsula, An Xuyen Province. The total mangrove area is approximately 716,000 acres (2900 km^2). On the land side of the mangroves, Melaleuca woodlands, with the small tree "Tram" (Melaleuca leucadendron) as the dominant species, cover areas on wet sandy and muck soils, mainly south of Rach Gia (U-Minh Forest), in small clusters inland on the Plain of Reeds, and on the Cam-Ranh Peninsula. Its total area is about 469,000 acres (1900 km^2).

Savannas of grass and scattered trees, and treeless grasslands, occupy large areas formerly covered by forests, probably as a result of swidden operations and frequent fires. Savannas are found in the plateau area of the Central Highlands. Grasslands are found near the savannas on mountain summits.

Forests classified as Closed and Open form 63 percent of the land area of SVN. In this report, these forests are referred to as Inland Forests. Mangrove forests and Melaleuca woodlands account for about 3 percent of the land area of SVN. If Savannas are classified under Forests, as done by Rollet, the forests of all kinds account for about 71 percent of this area.

Barren lands of sand dunes and brush land are found on the sandy part of the coast from Vung Tau north to the Demarcation Line. Dense clumps of small, thorny deciduous trees and brush are often found back of the sand dunes. Grass and sedge swamps are characteristic of considerable areas of the Mekong Delta region, the latter particularly on the "Plain of Reeds."

Land under permanent cultivation including tree crops covers approximately 19 percent of the land area of SVN. Two-thirds of this area is located in the Mekong Delta, the remainder mostly in the coastal lowlands and in valleys scattered throughout the Central Highlands. Rice grown in irrigated fields is the most important crop; important tree crops are coconuts and rubber.

REFERENCES

Moormann, F.R., 1962. The Soils of the Republic of Vietnam. Ministry of Agriculture, Directorate of Studies & Research in Agronomy, Forestry and Animal Husbandry, Saigon.

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

Viet Nam Statistical Year Book, 1971. (17th Volume) National Institute of Statistics, Republic of Viet Nam, Ministry of National Planning & Development, Saigon.

III. INVENTORY OF HERBICIDE OPERATIONS AND THEIR RELATION TO VEGETATION

The Committee wanted to produce estimates of the total areas in SVN that had been sprayed with herbicides for military purposes, breaking them down by herbicide type, stated military objective, and dates and frequency of spray applications. This information was to be related to vegetation types, soil types, population distribution, and land-use patterns.

Thus, two series of questions had to be addressed. One of these related to the distribution of herbicides throughout SVN: where, how much, what kind of herbicides were sprayed, what area was covered and how much of it was covered once, twice, three times, etc.; what was the intended purpose? For this information we relied primarily on records and descriptions of herbicide operations. As far as possible accuracy and completeness of this information were checked by examining the internal consistency of the available records and by examining aerial photos for evidence that missions were carried out as recorded.

The second series of questions related to the characteristics of the sprayed areas before defoliation: what were the types of vegetation, population, land-use; what was their distribution in space and quantity in SVN before the herbicide operations? Some maps and aerial photographic information existed, but it was often not of the appropriate date nor of the appropriate scale to be of much use for the tasks outlined above. Ideally, we also wanted to know what changes were taking place in the relevant features of the environment and the human population simultaneously within but unrelated to the defoliation program. It was known, for example, that there were many acts of war, such as bombing, shelling, clearing of vegetation by so-called Rome plows (super-bulldozers); and that there were other acts of man indirectly related or unrelated to war, such as rapid urbanization and resettlement, continued cutting of lumber and firewood, and continued clearing of the forest for agriculture, which would also influence distribution of vegetation types, land-use, and population. Similar disturbances have been taking place for a long period of time. Where had such changes taken place, at what rates, and could herbicide-induced changes be distinguished from effects of other causes?

In this section, the materials and information available, the procedures for analysis, the results, and their limitations, are discussed. No work could be done on the relation of the herbicide operations to population distribution as the necessary material (HES tapes) were received from DOD too late.

A. Principal Material Used

(1) Vegetation and Soils Maps

As a starting point for establishing the impact of herbicide sprays on different vegetation types use was made of 1:1,000,000 scale vegetation map prepared by Rollet (1956) on the basis of aerial photography, 1:40,000 scale, made in 1952-53 by the French National Geographic Institute. In 1962 Rollet prepared a "note" (memorandum) on this map in which he distinguishes twenty vegetation types as follows (transl. from the French):

1. Dense forest.
2. Secondary forest with swidden agriculture zones and bamboo forests.
3. Mixed dense and secondary forests.
4. Open dipterocarp forest.[a]
5. Semi-dense *Lagerstroemia* and more or less open Leguminosae forests, including patches of pure stands of *Lagerstroemia* and of semi-dense forests.
6. Tree or shrub savannas on various soil types.
7. Very degraded, dry, spiny forests in the region of Phan-Thiet, Phan-Ri, Phan-Rang on white and red sands or old alluvium.
8. Stands of *Pinus khasya* (three-leaved pine).
9. Stands of *Pinus merkusii* (two-leaved pine).
10. Grass steppes or grasslands, Pleiku-Dalat.
11. Grass steppes or grasslands with sterile patches, on the Three-Frontier Highland.
12. Prairies (at higher altitudes).
13. Mangrove.
14. Dune vegetation on seashores.

---

[a] The families Dipterocarpaceae and Leguminosae, and the genus *Lagerstroemia* are important elements of the forests of Southeast Asia.

15. Cultivated areas: rice fields, plantations, vegetable gardens.

16. Marshy prairies (in Terrace and Highland Regions).

17. Vegetation of the Plain of Reeds: marshy prairies, rice fields, abandoned rice fields, patches of stunted Melaleuca leucadendron.

18. Dwarf shrub formations: abandoned crop land with patches of Melaleuca leucadendron, frequent south of the Mekong; old rice fields.

19. Pure stands of Melaleuca leucadendron on peaty soils (U-Minh) or sandy soils along the seashore or behind the mangrove particularly in the Ha-Tien region.

20. Vegetation of lime soils.

Rollet's map is reproduced in the Map Section, but in a simplified form, combining certain of his types, as the reduction in scale would not permit clear appearance of all 20 types and their mixtures.

For soils, a map prepared by Moormann (1961) was used; a summary of the soil types with typical locations, land-use and vegetation cover is given in Table II E-1 and a simplified map reproduced in the Map Section.

(2) Aerial Photography

It was impossible to do intensive field work in affected forests; and even if it had been possible we would have hardly been able to cover all affected areas of the country in a comprehensive, quantitative manner. Thus, extensive use was made of aerial photography, but because of limitations of time and other resources, the Committee decided to confine aerial photographic study to a number of selected objectives: selected areas of one of the major inland forest areas in SVN, in the Terrace Region northwest to northeast of Saigon, as this area was of great commercial importance and had been exposed to heavy herbicide spraying (see Section IV); some selected areas in which crop destruction missions had been flown (Section III); and selected areas for the study of effects of herbicide operations on settlements and people (Section VII B and C). The main photography used for inventory work was:

1. 1958: black and white coverage, 1:50,000 scale, of the southern portion of the country, particularly the Terrace Region, from the World Wide Survey (WWS) Project 166.

2. 1968-69: partial coverage of inland forest areas in the Terrace Region of SVN flown by DOD for various purposes, black and white, 1:50,000 or less.

3a. 1972: color, black and white, and color infrared coverage, 1:5,000, of selected sample strips in the Terrace Region and Rung Sat Special Zone, made in the wet season (October).

3b. 1973: (repetition of 3a), together with 1:50,000 black and white photography of the same sample strips, made in the dry season (January-February).

3c. 1973: special 1:5,000 and 1:10,000 black and white and color photography of selected study areas, mainly such areas which showed effects of heavy herbicide exposure.

4. DOD photography of selected areas of the inland forests made between the dates shown above, to study sequentially changes occurring in these areas.

5. DOD photography in a number of study areas for studies of crop destruction missions and of effects of herbicide missions on different settlement types. The photography under 4) and 5) was in black and white and at scales ranging between about 1:50,000 and 1:4,000.

(3) Herbicide Mission Tapes

The main source of data for herbicide missions was the so-called HERBS tape and printouts of this tape obtained from MACV through DOD. The source for the data on the tape is a log book which was maintained at Headquarters, MACV, at Saigon. The data in the log book were transferred to punch cards, and the tape prepared from these cards. The data were on a mission-by-mission basis and were derived from reports and files in various Commands and offices in SVN and the U.S. which in turn went back to, or included the planning records and the mission commanders' reports which were prepared before and after each mission (Section II B).

The Committee's version of the HERBS tape includes date, project, or mission number, location (province and coordinates in the UTM[a] system, type (Orange, White, Blue) and the quantity of herbicide, area covered, purpose of mission (defoliation, crop destruction, or other), and type of aircraft (fixed-wing or helicopter). One of the printouts shows also the number of aircraft per mission. The Committee's copy of the tape covers the period August 1965 (when the log book was started), through February 1971 and lists a total of 6542 missions. The HERBS tape is the source of all mission maps in this report and unless otherwise specified of all tabulations of herbicide operations. An additional printout covered the period March 1971 to October 1971 when, according to information from DOD, U.S. controlled herbicide operations ended.

---

a Universal Transverse Mercator. This system identifies points by coordinates with two letters, representing a 100,000 by 100,000 meter quadrangle, followed by a four or six digit number, representing the distance in thousands or hundreds of meters from the lower left (southwest) corner of the quadrangle.

B. Procedures and Results of Herbicide Inventories of Operations and their Relation to Vegetation

(1) Herbicide Mission Maps

The herbicide mission records stored on the HERBS computer tape include, for each mission, the geographic location of the beginning and end of each mission and in some, but not all records, points of change in flight direction. Four missions had incomplete entries, and three of these lacked some essential information for use in mapping (no location, gallonage, area sprayed) and had to be excluded. The data for the remaining 6539 were fed to an automatic drafting machine which drew a line representing each mission on a map. The herbicide agent used was represented by the color of ink used in drawing the line. Separate maps were drawn for each year, and for missions classified as defoliation, crop destruction, and the other classes noted in Section II B (3).

Upon inspection of the maps it was obvious that some mission records were in error. A number of the plotted lines represented missions greater than 100 km long, while the capacity of the aircraft limited mission length to about 12 km. A few missions were represented as being over the ocean. The data on the HERBS tape referring to overly long missions, or those over water were individually inspected, and where the source of the error appeared obvious (for example a mistake in identification of the UTM quadrant identification) the record was corrected. From the original total of 6542 missions recorded on the HERBS tape, 880 (13.6 percent) were considered to be in error; of these 575 were corrected, while the errors in 305 could not be corrected and had to be omitted from the mapping of the HERBS tape data. Our correction procedure resulted in a figure for total number of missions that is about 4.6 percent lower, in a number of gallons that is about 3.5 percent lower, and a number of acres that is about 7.5 percent lower than in the uncorrected tape (see Table III B-1, compare UNC and COR figures).

After this screening and correction of the mission data, the final series of spray mission maps was drawn. A map for all herbicide defoliation missions on the HERBS tape, and a map for the herbicide crop destruction missions are located in the Map Section. The main limitation of these maps is that the plotted lines represent only the center line of each mission. Some missions were flown by one aircraft and the resulting swath would be 80 m (264 ft) wide, but many missions were by three aircraft and some by as many as six resulting in swaths of 240 m and 480 m in width, respectively. These differences in effective area of spraying are not represented by the maps. Special "impact frequency" maps, noted later, were made to show how many times any sprayed hectare had been sprayed due to repetition or overlapping of herbicide applications. The scale of the maps in the Map Section is far too small to label each individual mission, but this was also done on much larger maps for use in detail studies, and a number of such maps are shown in later sections of this report (e.g., Sections IV B, IV C, VII B [1], VII B [3]).

Table III B-1

Herbicides used for military purposes in SVN, as recorded on the uncorrected and corrected HERBS tape (August 1965 through February 1971).
(The acreage is the sum acreage covered by all missions, regardless of whether sprayed once or repeatedly.)

Listed Mission Objective	UNC[a] COR	Agent Orange No. Missions	Agent Orange Gallons	Agent Orange Acres	Agent White No. Missions	Agent White Gallons	Agent White Acres	Agent Blue No. Missions	Agent Blue Gallons	Agent Blue Acres	TOTAL No. Missions	TOTAL Gallons	TOTAL Acres
Defoliation	UNC	3,047	10,060,952	3,273,095	1,354	5,000,215	1,650,910	160	441,325	141,131	4,561	15,502,492	5,065,136
	COR	2,962	9,788,802	3,103,693	1,324	4,894,215	1,580,439	157	430,525	138,287	4,443	15,113,542	4,822,419
Crop Destruction	UNC	477	968,285	336,714	56	56,060	18,406	325	596,814	289,105	858	1,621,159	644,225
	COR	427	881,570	265,201	45	51,150	16,149	240	493,623	176,386	712	1,426,343	457,736
Perimeter[c]	UNC	337	99,517	33,172	242	100,566	33,522	111	46,902	15,634	690	246,975	82,325
	COR	335	98,967	32,989	241	99,456	33,152	108	44,002	14,667	684	242,425	80,808
Cache Site[c]	UNC	111	49,525	16,508	79	50,313	16,771	17	3,640	1,213	207	103,478	34,492
	COR	101	43,080	14,360	76	47,133	15,704	17	3,640	1,213	194	93,853	31,284
Waterways[c]	UNC	60	33,310	11,103	24	14,970	4,990	8	5,025	1,675	92	53,305	17,768
	COR	51	25,405	8,468	23	13,980	4,660	7	4,575	1,525	81	43,960	14,653
Friendly Lines[c] of Communication	UNC	43	25,255	8,418	20	17,230	5,743	16	19,351	6,450	79	61,836	20,612
	COR	42	24,555	8,185	19	17,190	5,730	16	19,351	6,450	77	61,096	20,365
Enemy Lines[c] of Communication	UNC	33	21,885	7,295	11	7,158	2,386	3	11,250	3,750	47	40,293	13,431
	COR	32	21,635	7,211	10	4,820	1,607	3	11,250	3,750	45	37,705	12,568
Not Stated[b]	UNC	1	2,700	592	0	0		0	0		1	2,700	592
	COR	1	2,700	592	0	0		0	0		1	2,700	592
Total	UNC	4,109	11,261,429	3,686,305	1,786	5,246,502	1,732,728	640	1,124,307	458,958	6,539	17,632,238	5,878,581
	COR	3,951	10,886,714	3,440,107	1,738	5,127,944	1,657,441	548	1,006,966	342,278	6,237	17,021,624	5,440,425

[a] UNC = Uncorrected tape, COR = corrected tape. See text (Section III B[1]) for these corrections.

[b] For three more missions, agent type, gallonage and acreage were also missing. These missions are not included in the totals shown; the grand total in the table is therefore 6539 rather than the total of 6542 appearing on the HERBS tape.

[c] Acreage calculated on the basis of 3 gal./acre application rate and on the known amount of herbicide use.

(2) Aerial Photography Interpretation

Only general notes on aerial photographs are given here; more extensive discussion is contained in the chapter on Quantitative Assessment of Herbicide Damage to the Inland Forest (IV B [3]).

Aerial photographs are among the most effective means of conducting extensive surveys of vegetation and other visible features on the land. Consequently, both civilian and military methods for obtaining and analyzing aerial photographs have been developed to make use of modern technology. Interpretation and measurements can be made with a high degree of accuracy.

In general terms, photographic coverage was studied for the area of MR III (Fig. III B-1) to determine for that area the condition of the mangrove and the inland forests before and after the period of herbicide spraying. In portions of the area detailed studies were made to discover the kind and degree of change in the vegetation from year to year throughout the period of spraying.

For the years 1958 and 1969 virtually complete coverage was available for MR III area. Individual points on photographs were matched and overlapped to produce a mosaic which is essentially a photographic map of an extensive area. Specimen photographs are given in Figs. III B-2 and B-3 to indicate what can be seen at scales of 1:50,000 and 1:5,000. In Figs. III B-4 through B-5 are examples of relatively dense forests of trees, and remnants of forest left after cutting and clearing for agriculture. Also shown are two general classes of forest, one of large trees forming a dense, even canopy (Fig. III B-4), the other composed of a scattering of large trees with many small trees and thickets covering the rest of the area (Fig. III B-5). The latter condition often results from selective harvesting of trees from what was originally a dense even-canopied forest. Areas of bamboo forest, also widely occurring, are illustrated in Fig. III B-6. Such differences are important in assessing the condition and value of a forest.

One important use of the photographs was to draw boundary lines around the many different types of vegetation over the land and to identify and measure the area of these (Fig. III B-7). Much of the photo coverage was made so that prints overlap in such a way that, when viewed through a stereoscope, the surface features can be seen in three dimensions--trees appear to stand up from the ground as one would see directly from an aircraft. By studying some areas in detail through the stereoscope an experienced photo interpreter can become familiar with the photographic appearance of the vegetation types and rapidly map extensive areas with only intermittent use of the stereoscope to maintain consistency and check difficult types. Ideally, of course, such maps should be verified by examination of the vegetation on the ground but this was not possible in our case because of the problems of safety which have already been mentioned (Section I B [3]).

Fig. III B-1. Military Regions of South Vietnam.
The CORPS on the map have been changed to Military Regions (MR).

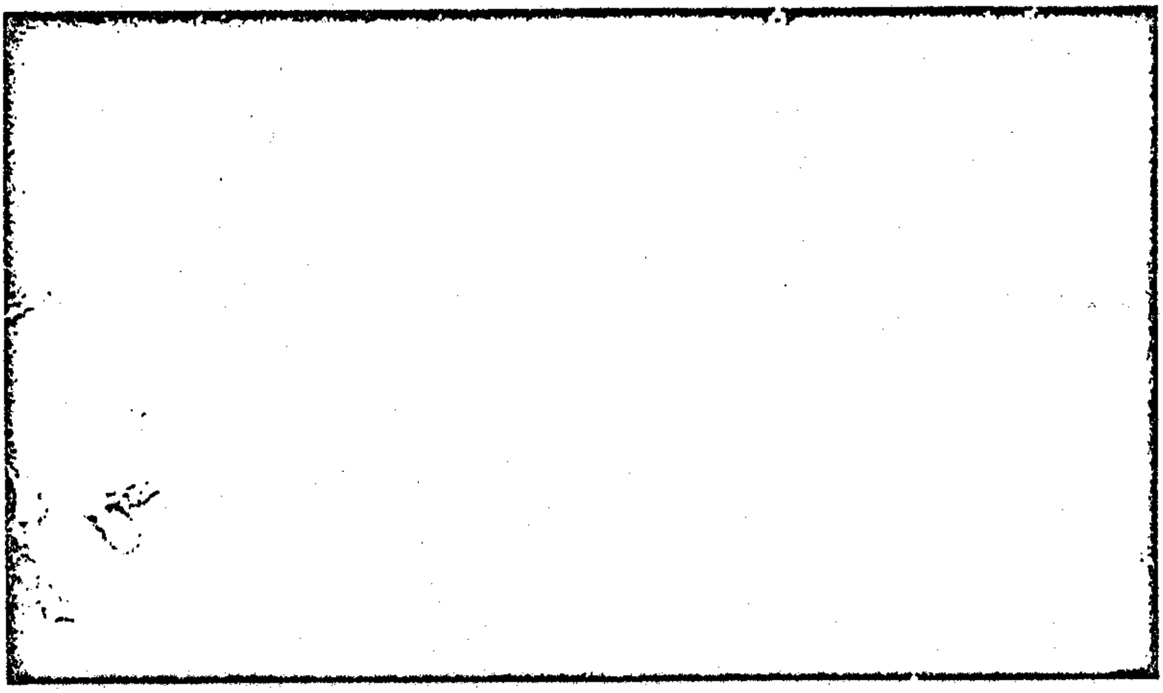


Fig. III B-2. Inland Forest at a scale of 1:50,000. 1958 photography (i.e., pre-spray). Part of the area of the right rectangle is seen below at a different scale fifteen years later.

Fig. III B-3. Inland Forest at a scale of 1:5,000. 1973 photograph flown for the Committee of an area that had been sprayed with herbicide.

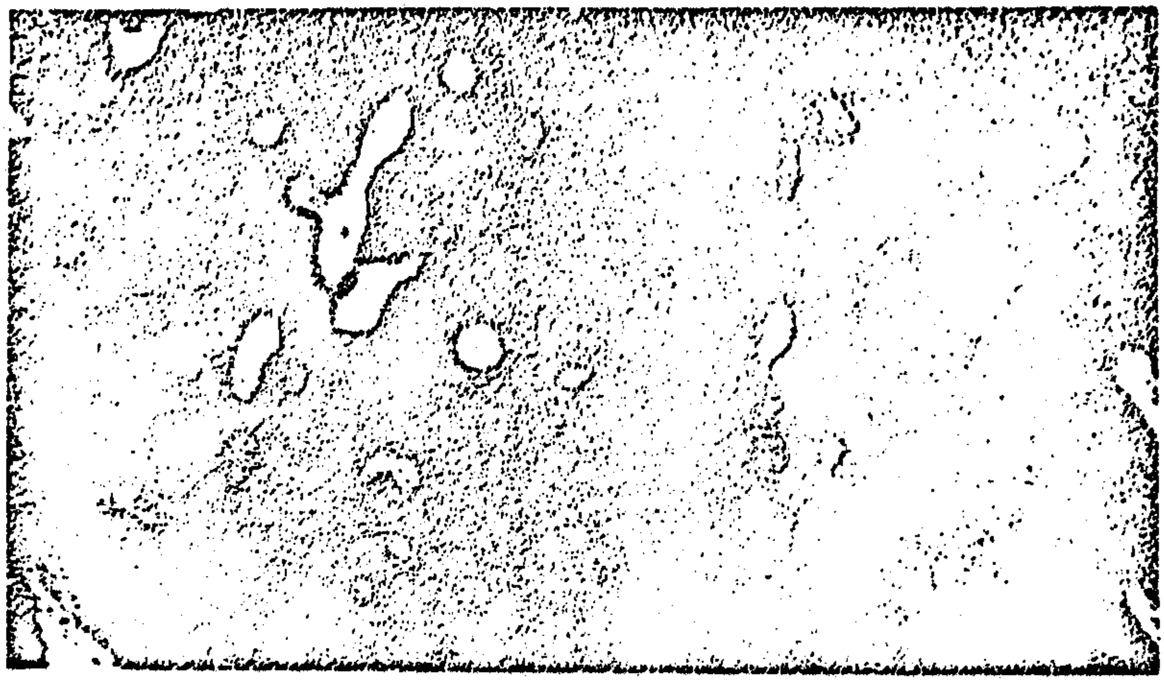


Fig. III B-4. Dense and relatively undisturbed secondary forest with swamp patches in the Terrace Region, North and Northwest of Saigon (XT quadrangle). 1958 photography (i.e., pre-spray), scale 1:50,000.

Fig. III B-5. Forest area in XT quadrant consisting of scattered large trees interspersed with many small trees, thickets, and patches of former agricultural land. Enlarged from 1958 photography.

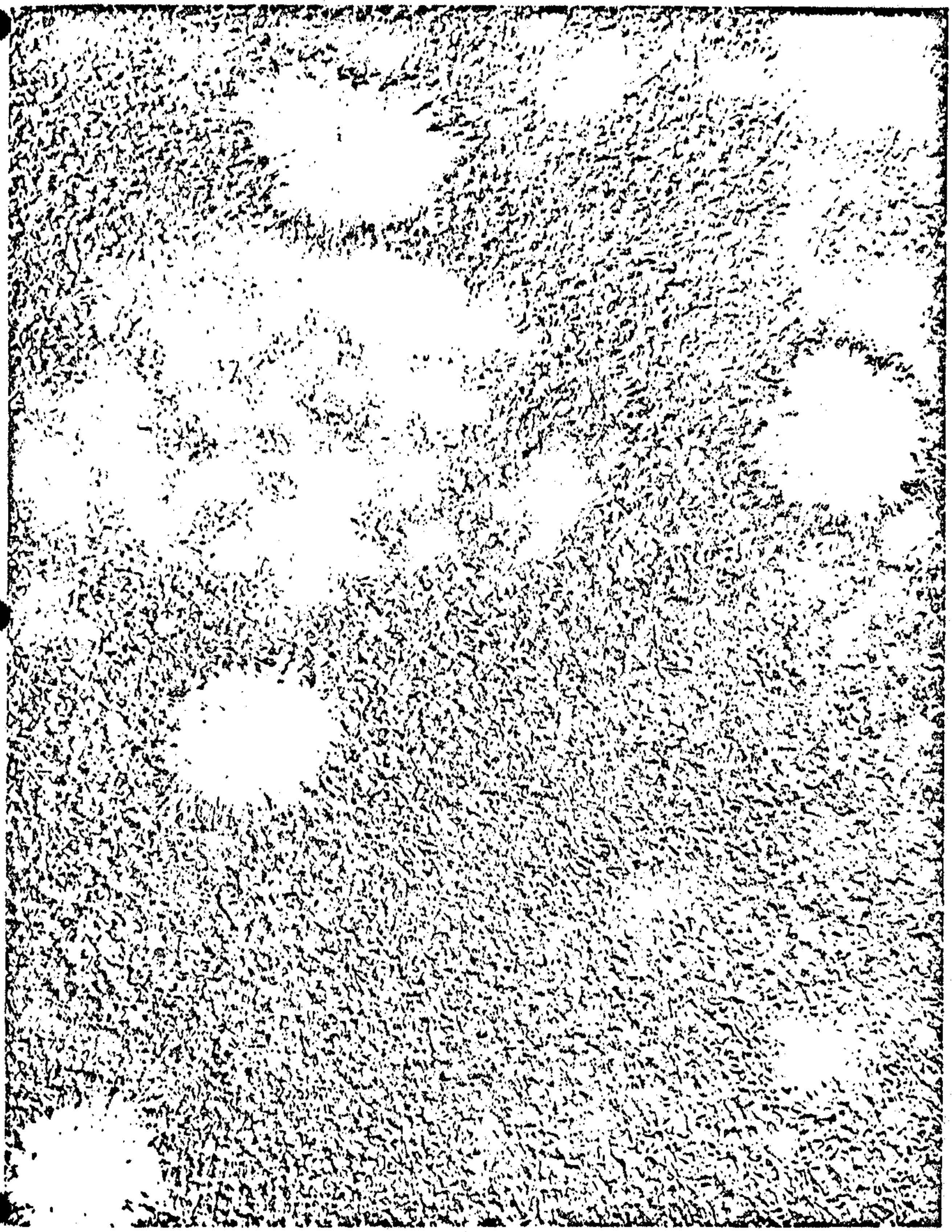


Fig. III B-6. Scattered Bamboo forests occur in the secondary forests north of Saigon. Note the large bomb craters and their effect on adjacent vegetation.

Fig. III B-7. Dense forest interspersed with areas of agricultural land and other disturbed areas. 1958 photography at a scale of 1:50,000. Outlines show delineation used for classifying different forest conditions as used in Section IV B.

In the mangrove, large areas of the tidal mud flats were covered by vegetation in 1958 photography. Where these mangrove forests were sprayed with herbicides, the result was a dramatic killing of the trees leaving a clearly defined rectangular swath of dead, brown trees and the exposed mud contrasting clearly with adjacent live mangrove (see Fig. III B-8). In the inland forest the effects generally were much less dramatic. In 1969 photos many spray swaths are visible as gray or white rectangular streaks; the light tone (on black and white photos) appears to fade with time due to refoliation and revegetation. Rarely are rectangular swaths of vegetation completely killed seen in the inland forest photographs. In the 1972-73 photographs (1:5,000 scale) dead trees are clearly visible, sometimes in solid clumps but more often scattered singly through forests of otherwise green trees.

While details are discussed at length in Section IV B (3), it must be noted that effects of herbicide are in many places difficult to assess because of the wide-spread and often heavily concentrated bombing as illustrated in Figs. III B-9 and B-10. Land clearing for both civilian and military purposes also changes the vegetation cover, and this had also to be considered.

Despite the effectiveness of aerial photo analysis, our studies have some important limitations. As it was impossible to go into the forest, it was not possible to check measurements and particularly to obtain information on what tree species were in the forests, how they were affected, and what recovery (seedlings and saplings) had occurred. The coverage was not uniform in quality or quantity; some areas had excellent and plentiful coverage but others did not, and it was thus not possible to obtain answers to the same degree about the effects in all parts of MR III. The degree of coverage is indicated by maps in Section IV B (3). Also, it was not feasible to study the entire area of SVN so that results of vegetation survey, herbicide effects, etc. had to be extrapolated from MR III photo studies to the whole of SVN.

(3) <u>Vegetation Mapping</u>

The vegetation map of Rollet (1956) was used in assessing, for the whole country, how much of each type of vegetation was sprayed by herbicide. For this purpose, the boundaries and identification of each segment of vegetation on the Rollet map was coded for processing by computer as described below (Data Bank).

The main limitation of the Rollet map for our objectives is that it was constructed as a general botanical map of broad vegetation zones at a scale of 1:1,000,000. In fairness to Dr. Rollet is must be said that in our study the map was extended far beyond its intended use. In this study it was particularly important to distinguish between

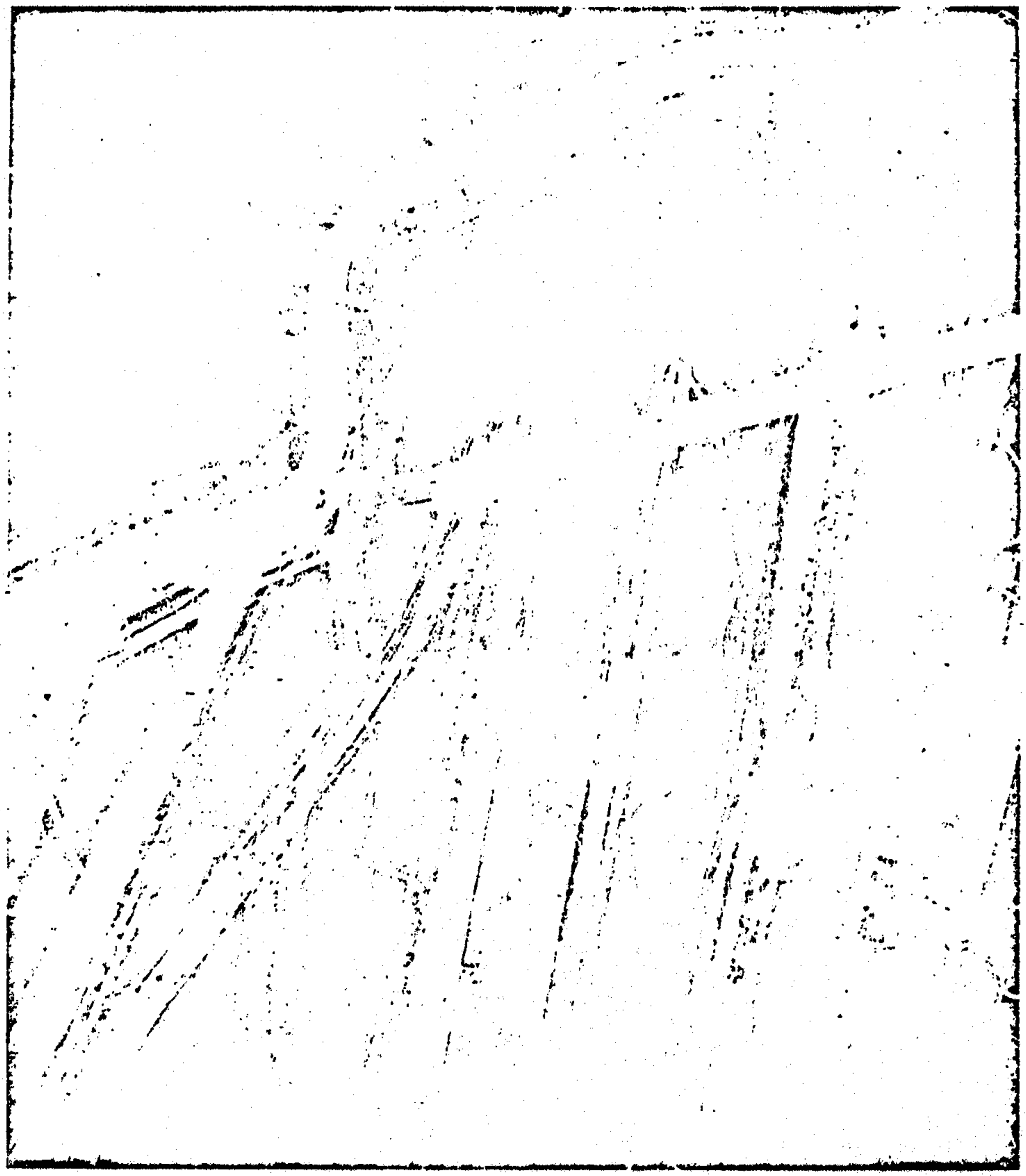


Fig. III B-8. Herbicide treated mangrove area in the Ca Mau Peninsula showing narrow strips of surviving vegetation between denuded areas. 1971 photography.

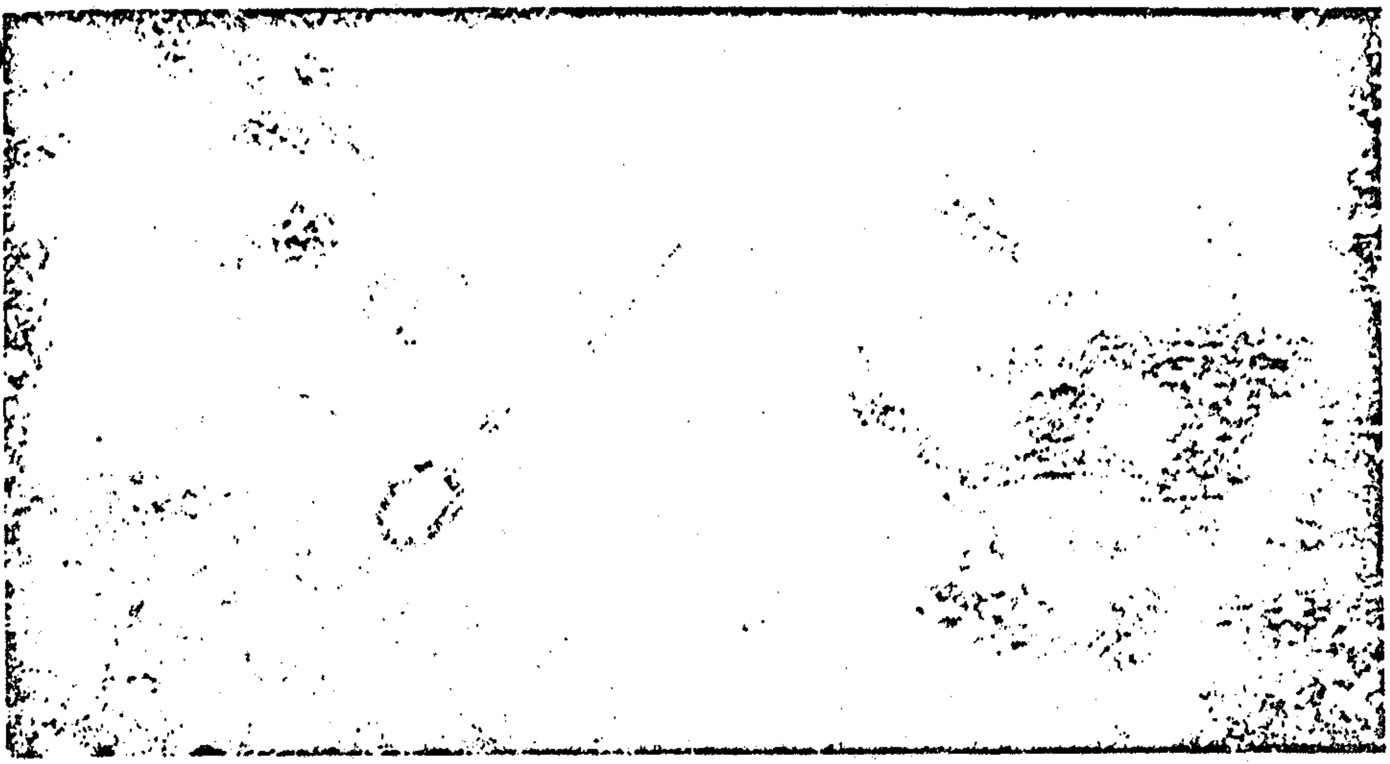


Fig. III B-9. Combination of heavy bombing and herbicide spray. 1969 photography at a scale of 1:50,000. Area heavily disturbed by agricultural use and logging.

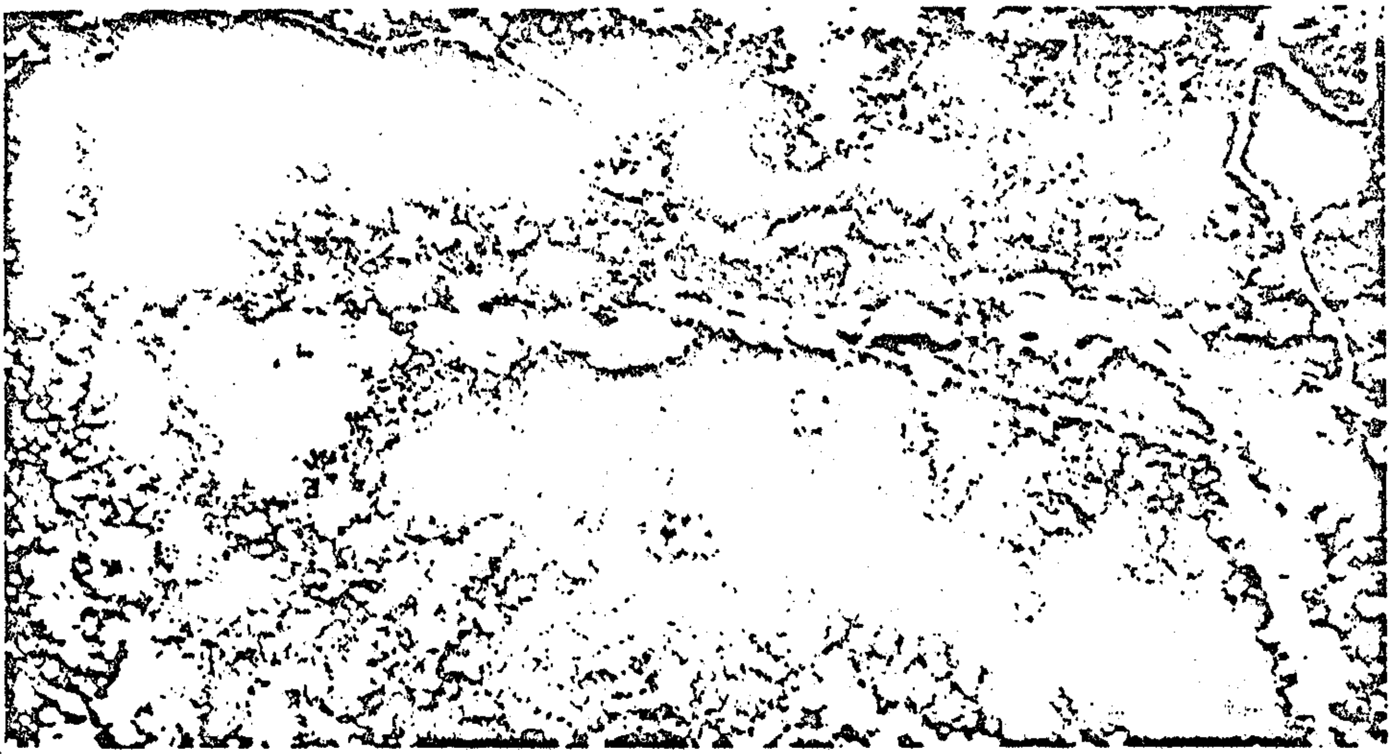


Fig. III B-10. Similar area as in Fig. III B-9 enlarged.

forest composed of trees, and forest composed mainly of bamboo or shrubs. Quite correctly from a botanical point of view, Rollet termed all of these vegetation types forest, but they are not distinguished separately in his map. From the aerial photographs it is evident that even many of the heavily timbered areas are interspersed with a patchwork mosaic of small areas of bamboo, shrubs, marshy openings (see Fig. III B-4), cultivated clearings, and that it would be impossible to map them at the 1:1,000,000 scale used by Rollet.

It was, therefore, necessary to superimpose the Rollet map on 1957 aerial photographs to discover the composition of Rollet's broad types when examined in detail. But this was done only for the MR III area where aerial photo coverage was studied. Results of this analysis are presented and discussed in Section IV B (3).

(4) Quantity of Herbicide Applied

The HERBS data tape included, for each mission, a record of the number of gallons of herbicide, the type of agent, and the purpose of the mission. These data are summarized in Tables III B-1 and B-2. In Table III B-1 are totals for all data recorded on the original HERBS tape, without and with the corrections and omissions noted in (1) earlier. In Table III B-2 the totals by year are presented. In Section III C, we will discuss in detail sources and amounts of error caused by using exclusively the HERBS tape data for determining the amounts of herbicides used and the areas sprayed.

The acreage figures for the "minor" missions (perimeter, cache sites, etc.) in Table III B-1 are calculated from the gallon figures, using the rate of 3 gal./acre. This is because almost all of these missions are identified by only one coordinate, which does not permit us to estimate the area. It should be noted, however, that the acreage figures for defoliation and crop destruction missions are also calculated figures, obtained by multiplying the length of the spray line by the nominal swath width of 80 m by the number of aircraft in the mission. In Table III B-2, figures from the corrected HERBS tape have been used which are 3.5 and 7.5 percent less than those in the uncorrected tape, for gallons and acres, respectively. Since it appears certain that, while the records of some missions on the HERBS tape were in error, the missions themselves were carried out, the higher figures are the more correct ones. The acreage figures, however, do not match those in Table III B-1 because the acreage calculation for the "minor" missions was not carried out for each year and these missions are thus not included in the acreage.

(5) Data Bank Analysis of Herbicide Application to Different Vegetation Types

The major objective of the Data Bank is to provide information on the type and amount of vegetation sprayed in a given location, and the type of agent(s), and number of applications of herbicide.

The missions included in our analysis were flown over a period of years (1965-1970) and repeated spray applications were made in many areas in

Table III B-2

Summary of herbicide missions by year and by agent
(from corrected tape)

The acreages are cumulative values (see Table III B-1)

	ORANGE			WHITE			BLUE			TOTAL		
	No. missions	Gallons	Acres	No. missions	Gallons	Acres	No. missions	Gallons	Acres	No. missions	Gallons	Acres
1965[a]	164	353,350	75,501	0	-	-	0	-	-	164	353,350	75,501
1966	618	1,520,890	412,941	182	514,375	190,740	6	15,800	4,425	806	2,051,065	608,106
1967	1,014	3,105,569	1,028,298	495	1,319,335	421,716	157	355,225	120,100	1,595	4,780,129	1,570,114
1968	755	2,168,377	659,803	604	2,075,998	628,279	112	271,015	77,397	1,471	4,515,390	1,365,479
1969	1,072	3,190,950	1,009,192	402	997,888	292,466	177	227,793	64,096	1,651	4,416,631	1,365,754
1970	328	547,578	183,921	112	208,173	63,567	90	134,803	47,487	530	890,554	294,975
1971[b]	0	-	-	14	12,175	15	6	2,330	1,244	20	14,505	1,259
Total	3,951	10,886,714	3,369,656	1,738	5,127,944	1,596,783	548	1,006,966	314,749	6,237	17,021,624	5,281,188

---

[a] from August only. A total of 195 projects with about 1,270,000 gal. were carried out prior to August 1965. The agents are mostly not recorded, but were mainly Purple and Orange. See Section III C (2) and Table III C-1.

[b] January and February only. A total of 31 additional missions (total 35,447 gal. of Agents White and Blue) were flown between March and October 1971. See Section III C (2) and Table III C-1.

[c] 159,237 acres were added to Table III B-1 for Perimeter, Cache Sites, Waterways, Friendly Lines of Communication, and Enemy Lines of Communication, increasing the total for the corrected tape to 5,440,425 acres.

crisscrossing flight patterns. These irregular patterns of overlap made it impractical to calculate the number of repeated applications on a given area by a direct analysis of navigation data. Instead of direct analysis, a systematic survey was made by computer to identify each individual hectare sprayed in each spray missions as follows.

The entire map of SVN, already subdivided into square of 100 km^2 (10 by 10 km or ca. 6 1/4 by 6 1/4 miles) for navigation reference, was further divided into single hectares (100 by 100 m or 2.5 acres). For each spray mission, the boundaries of its swath were computed from the navigation records. Then each hectare square having its center point inside the spray swath (see Fig. III B-11) was labelled in a computer record with information on the mission, date, identification, and herbicide agent. This was repeated for every defoliation and crop destruction mission.

Any hectare sprayed several times then has a record for each spray, so that a count can be made of the number of hectares having one, two or any other number of herbicide applications of any combination of herbicide agents (see example in Fig. III B-12). While this technique does not define the precise boundaries of the herbicide swaths, it is a sound procedure for estimating the number of hectares affected by the various combinations of herbicide agents.

The process outlined above yielded in excess of 2,000,000 computer records, one for each time a hectare was sprayed. To each of these records was added the vegetation type according to the Rollet map, identification of the province in which the hectare is located, and the type of soil according to the soils map of Moormann (1961).

These records were summarized to give the information listed in Tables III B-3 and B-4. Missions with erroneous records which proved to be uncorrectable (see above) were excluded. Also excluded were the "minor" missions since, as they are identified on the HERBS tape usually by one coordinate only, their precise location is not known. The corrected tape has 3.5 percent less gallons and 7.5 percent less acres for defoliation and crop destruction missions than the uncorrected version. The "minor" missions represent about 3 percent of the total gallonages and (as this was computed from the former) the total acreage of the uncorrected HERBS tape. Altogether, the excluded missions (the uncorrectable defoliation and crop destruction missions, and all "minor" missions) amount to about 1,070,000 gallons of herbicide and 600,000 acres of cumulative coverage, or somewhat over 6 and 10 percent, respectively, of the totals on the uncorrected HERBS tape.

From Table III B-3, the following can be seen:

(a) All of SVN. About 3,600,000 acres were sprayed. This is a little greater than the total area of Connecticut. About 2,370,000 acres or 66 percent of the sprayed area were sprayed once, about 800,000 acres or 22 percent twice, about 280,000 acres or 8 percent three times, and about 130,000 acres or 4 percent four or more times.

(b) Inland forests. Of the total area of about 26 million acres,[a] 2.67 million acres or somewhat over 10 percent were sprayed; of these, 1.7 million acres or about two-thirds once, 620,000 acres or about one-quarter twice, about 220,000 acres or 8 percent three times, and about 110,000 acres or 4 percent four or more times.

(c) Mangrove. Of the total area of about 720,000 acres, 260,000 acres or 26 percent were sprayed; of these about 140,000 acres or 54 percent once, 70,000 acres or 27 percent twice, about 30,000 acres or 11 percent three times, and about 20,000 acres or 8 percent four or more times.

(d) Cultivated land. Of the total area of 7.8 million acres, 260,000 acres or 26 percent were sprayed; of these about 200,000 acres or 77 percent once, 40,000 acres or 15 percent twice, 13,000 acres or 5 percent three times, and about 6,600 acres or 3 percent four or more times.

With regard to the cultivated land, it must however be realized that small pieces of cultivated land in the inland forests, particularly swidden, could not be identified in our analysis but are rather included in the inland forests category.

[a] This excludes the pine forests.

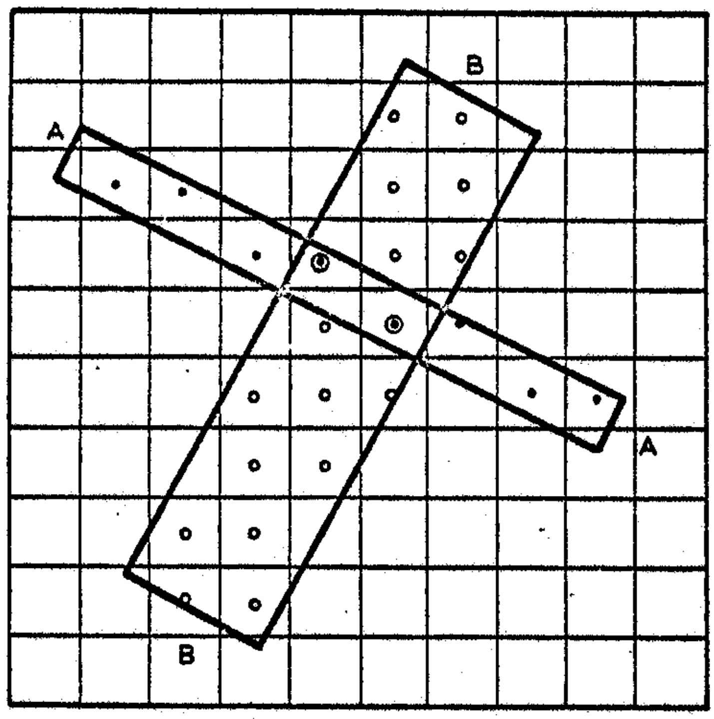


Figure III B-11. Diagrammatic representation of procedure for determining multiple herbicide spraying. Shown are a grid of one hundred single hectare squares and two herbicide mission swaths (A-A, B-B) as recorded from the HERBS tape. Hectares marked • are recorded as affected by mission A-A, those marked ° as affected by mission B-B, those marked ⊙ as affected by both missions.

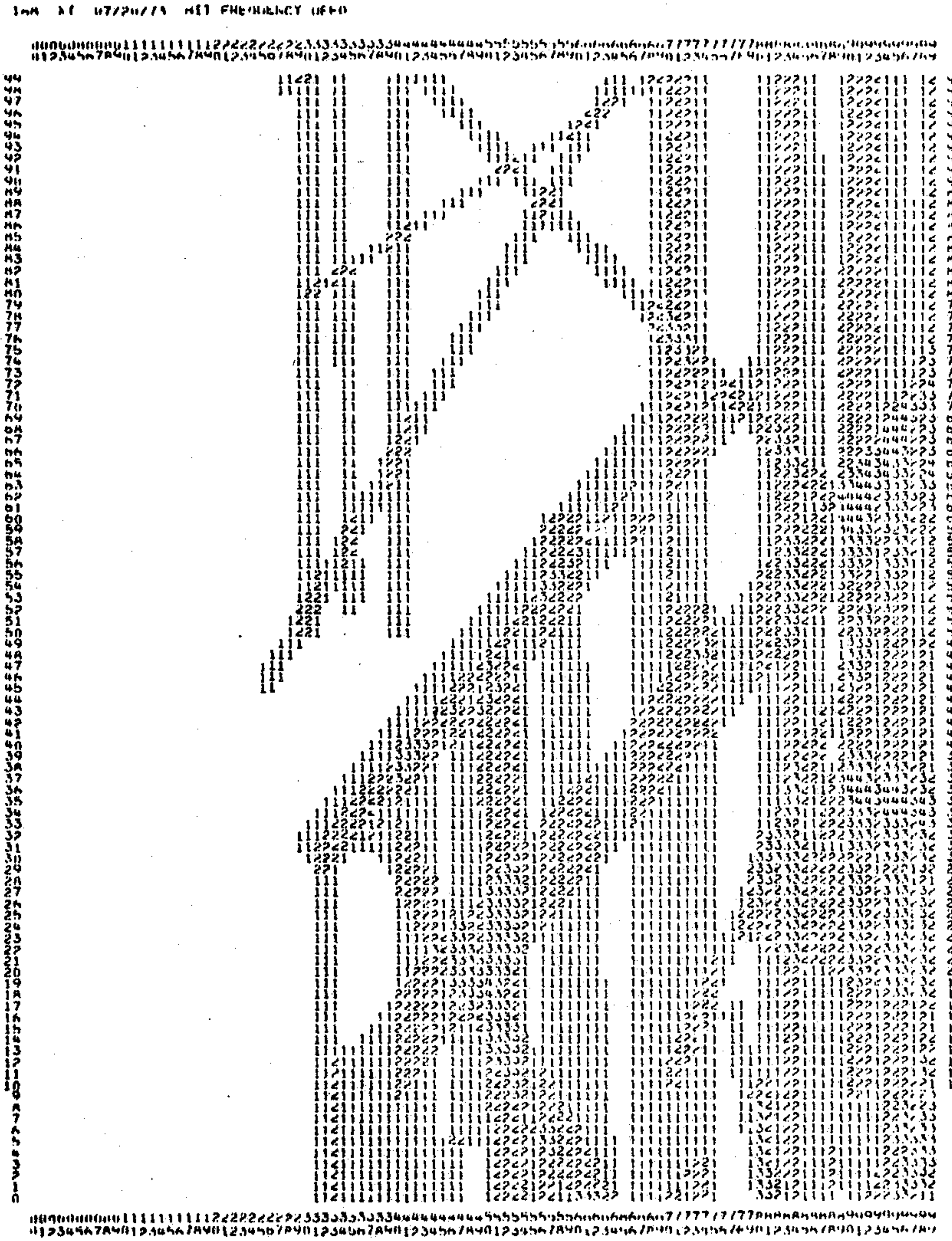


Fig. III B-12. Example of a computer "map" of herbicide missions over an area of 100 by 100 hectares. The figures on the outside ("frame") are counts of the hectares; in the body of the "map," each figure stands for one hectare (ca. 2.5 acres) sprayed once, twice, etc., no figure meaning no spray.

Table III B-3

Herbicide missions, as recorded in HERBS tapes, according to vegetation type and multiplicity of sprays, in acres.

A. Defoliation Missions

Vegetation type (with Rollet's numbers)	Number of sprays and agents: Single — Orange or White	Single — Blue	Twice — Orange and/or White only	Twice — Blue only	Twice — One Orange or White and one Blue	Three Times — All	Four or more times — All	TOTAL
Inland forests exclusive of pine forests: Dense forests (1)	653,742	14,727	261,254	919	7,052	99,954	45,528	1,083,178
Inland forests exclusive of pine forests: Secondary forests, swidden zones, bamboo forests (2)	655,052	15,829	240,631	2,444	11,201	93,073	47,250	1,065,480
Inland forests exclusive of pine forests: Dipterocarp, *Lagerstroemia*, Leguminosae forests (4,5)	142,100	3,588	52,276	279	5,451	20,507	9,726	233,927
Inland forests exclusive of pine forests: Total (1,2,4,5)	1,450,894	34,144	544,161	3,642	23,704	213,534	102,504	2,382,583
Pine forests (8,9)	146	-	5	-	-	0	0	151
Savanna and degraded forests in higher elevations (6,7)	47,584	133	12,849	-	7	2,357	378	63,308
Grasslands and steppes in higher elevations (10,11,12)	17,853	613	6,249	-	27	2,377	887	28,006
Mangrove forests (13)	141,237	2,468	61,995	37	4,156	29,133	20,276	259,302
Melaleuca woodlands (19)	46,622	2,641	10,116	54	781	2,157	200	58,571
Dunes and brushland (14)	14,836	106	3,081	-	242	474	44	18,783
Grass and sedge swamps, Plain of Reeds vegetation; dwarf shrub formation in Delta (16,17,18)	72,613	2,464	18,528	185	1,347	6,217	1,104	102,458
Cultivated land (15)	164,146	9,988	33,097	67	3,484	12,026	6,217	229,025
Non-vegetation	79,144	697	12,088	0	810	3,027	685	96,451
Total	2,031,075	53,254	712,169	3,985	34,558	271,302	132,295	3,238,638

B. Crop Destruction Missions

Vegetative type with (Rollet's numbers)	Number of sprays and agents: Single – Orange or White	Single – Blue	Twice – Orange or White only	Twice – Blue only	Twice – 1 Orange or White and 1 Blue	Three times – Orange and/or White	Three times – 1 Blue, 2 Orange and/or White	Three times – 2 Blue and 1 Orange or White	Three times – 3 Blue	Four or more	TOTAL
Inland forests exclusive of pine forests: Dense forests (1)	85,118	29,753	4,544	1,339	3,047	531	252	47	32	173	124,836
Inland forests exclusive of pine forests: Secondary forests, swidden zones, bamboo forests (2)	100,095	80,972	4,893	4,991	6,079	410	558	507	413	166	199,084
Inland forests exclusive of pine forests: Dipterocarp *Lagerstroemia*, Leguminosae forests (4,5)	8,041	4,230	208	106	81	0	0	42	12	0	12,720
Inland forests exclusive of pine forests: Total (1,2,4,5)	193,254	114,955	9,645	6,436	9,207	941	810	596	457	339	336,640
Pine forests (8,9)	190	455	10	0	0	0	0	0	0	0	655
Savanna and degraded forests in higher elevations (6,7)	14,843	12,214	1,023	358	309	94	15	2	7	2	28,867
Grasslands and steppes in higher elevations (10,11,12)	3,655	3,309	143	67	282	0	0	17	0	10	7,483
Mangrove forests (13)	1,097	0	637	0	0	0	0	0	0	0	1,734
Melaleuca woodlands (19)	0	0	0	0	0	0	0	0	0	0	0
Dunes and brushland (14)	1,025	843	20	5	69	0	15	2	0	7	1,986
Grass and sedge swamps, Plain of Reeds vegetation; dwarf shrub formation in Delta (16,17,18)	2,162	675	59	0	17	0	0	0	0	0	2,913
Cultivated land (15)	16,850	15,209	1,804	872	1,137	511	128	146	2	94	36,753
Non-vegetation	4,240	1,080	20	35	163	0	0	69	5	2	5,614
Total	237,316	148,740	13,361	7,773	11,184	1,546	968	832	471	454	422,645

Table III B-3 (cont'd)

Defoliation and Crop Destruction Missions, as recorded in HERBS tapes, according to vegetation type and multiplicity of sprays, in acres.

C. Total All Missions

Vegetative type (with Rollet's numbers)	Number of sprays and agents: Single — Orange or White	Single — Blue	Twice — Orange and/or White only	Twice — Blue only	Twice — One Orange or White and one Blue	Three Times — All	Four or more times — All	TOTAL
Inland forests exclusive of pine forests: Dense forests (1)	704,792	40,254	269,652	2,873	11,510	104,113	48,137	1,181,331
Inland forests exclusive of pine forests: Secondary forests, Swidden zones, bamboo forests (2)	725,054	88,767	248,699	7,220	21,309	98,531	49,889	1,239,469
Inland forests exclusive of pine forests: Dipterocarp, <u>Lagerstroemia</u>, Leguminosae forests (4,5)	148,654	7,612	53,779	385	5,627	20,990	9,843	246,890
Inland forests exclusive of pine forests: Total (1,2,4,5)	1,578,500	136,633	572,130	10,478	38,446	223,634	107,869	2,667,690
Pine forests (8,9)	336	454	15	0	0	0	0	805
Savanna and degraded forests, in higher elevations (6,7)	60,110	11,154	13,536	358	867	3,088	511	89,624
Grasslands and steppes in higher elevations (10,11,12)	20,896	3,824	6,296	67	378	2,537	971	34,969
Mangrove forests (13)	141,363	2,465	62,708	37	4,132	29,255	20,348	260,308
<u>Melaleuca</u> woodlands (19)	40,152	2,640	9,838	57	780	2,070	198	55,735
Dunes and brushland (14)	14,869	551	3,174	5	585	677	84	19,945
Grass and sedge swamps, Plain of Reeds vegetation; dwarf shrub formation in Delta (16, 17,18)	70,726	2,821	18,446	185	1,662	6,219	1,104	101,163
Cultivated land (15)	175,526	23,087	35,412	963	6,242	13,365	6,634	261,229
Non-vegetation	68,340	2,198	12,103	35	919	3,107	694	87,396
Total	2,170,818	185,827	733,658	12,185	54,011	283,952	138,413	3,578,864

Table III B-4

Tabulation of double and triple sprayed areas (in acres) by time intervals between the sprays (Defoliation missions only.)

Months between first and second spray	Months between second and third spray					
	None[a]	<1	1-3	4-6	7-12	>12
Less than one	140,308	14,492	21,646	7,015	12,647	31,149
1-3	203,037	20,887	28,397	12,829	23,272	37,179
4-6	82,405	10,522	8,802	4,947	11,097	13,309
7-12	112,665	16,420	18,009	5,728	11,836	13,487
>12	212,140	18,068	26,338	9,872	15,545	10,097

[a] That is, only two sprays.

Table III B-3 also includes information on the types of agents used in multiple sprayings, separating on the one hand Orange and White, on the other hand Blue, since the biological specificity is different (the two former being more selective, affecting mainly broadleaf plants, whereas the latter affect also grasses including cereal crops such as rice). Table III B-4 conveys an impression of the "density" of multiple sprays, that is the time intervals between consecutive sprays. This is an important factor in the effect of such sprays on the vegetation.

The Herbicide Mission Maps (Maps Section) and Tables III B-3 and B-4 indicate certain differences between defoliation and crop destruction missions. Firstly, Agent Blue was used relatively much more frequently for the latter than for the former. The crop destruction missions account, despite their much smaller number, for about one-half of the use of Agent Blue in the herbicide operations in SVN. On the other hand, it is worth noting that almost twice as much Agent Orange as Agent Blue was used on crop destruction missions. Secondly, defoliation missions, while by no means randomly distributed, have occurred practically over all regions of the country, with concentrations northeast and north of Saigon and further north along the border and the demarcation line, in the mangrove regions, and the U-Minh Forest. Crop destruction missions were concentrated in the northern three-quarters of the country (generally along upland and mountain valleys). Only four missions classified as crop destruction were flown in MR IV which largely coincides with the Delta Region. Thirdly, the density of crop destruction missions in both space and time was less than that of the defoliation missions. Less than 10 percent of the targets of crop destruction missions were sprayed more than once, and the intervals were usually 6 to 12 months or more. (For this reason, crop destruction missions have not been included in Table III B-4 which shows the timing of multiple sprays).

The main limitation of the data on relation of herbicide missions to vegetation types is that the vegetation types on the Rollet map are very general and their location not as precise as to permit exact identification on the aerial photographs. The vegetation types and their location thus should both be refined. This was done for one area for a more meaningful assessment of the herbicide damage to inland forests; the results are given in Section IV B (3).

(6) Analysis of Herbicide Operations over Cultivated Land

Of particular interest to the Committee was the extent and impact of the herbicide operations on cultivated land. Several attempts were made to approach this question: tabulation of the missions in the HERBS tape designated "crop destruction"; tabulations of all missions in the tape over vegetation classified as cultivated land (Rollet's type 15); and attempts to use aerial photographs in combination with HERBS records to determine the actual paths of various types of missions with reference to land use. It is clear from each of these approaches, as well as from interviews conducted in several parts of the country (see Sections VII B and C) that there were substantial cultivated areas hit by herbicides, partly directly and partly in the form of drift, but for reasons discussed below we were not able to make a quantitative estimate of the area or extent of damage to cultivated land.

It should be noted that damage to cultivated land cannot be estimated as easily or as appropriately by the methods used to estimate damage to forest. The reasons for this are: (1) Cultivated plants cover a smaller portion of the land than does vegetation classed as one or another type of forest. (2) Except for the Delta, farms in SVN may be scattered or discontinuous, often limited to small or narrow pieces of suitable land. These small cultivated areas could not be accommodated in the vegetation types in Rollet's map, and if sprayed appeared under other vegetation types (mainly inland forest). (3) The location of some cultivated areas, especially in the Highlands, is not permanent. (4) Another difficulty is the impossibility of distinguishing cultivated or uncultivated food plants (e.g., fruit trees) which are utilized but may have the appearance of being "natural" or "forest" vegetation. Fruit trees, bamboo and other useful species are grown in areas around villages or hamlets in the Highlands but because these are not planted as gardens or plantations in regular rows, they will be classified simply as forest vegetation.

The herbicide records distinguish between defoliation and crop destruction missions. Thus, the first question that comes to mind when one wants to assess the extent of herbicide exposure to cultivated land and its effects, is whether this distinction provides a basis for such an effort, or is at least of help.

There were 858 herbicide missions in the HERBS tape designated as "crop destruction," which covered a total of 644,225 acres (uncorrected). When apparently incorrect records were deleted or corrected, totals were 712 missions and 457,736 acres; when acreage was corrected for area sprayed more than once by crop destruction missions, the total was 422,000 acres (about 680 mi^2, or 1690 km^2). However, most of the area sprayed for crop destruction (337,000 acres, or 80 percent) was classified as inland forest, while only 36,753 acres (under 9 percent) was classified as (permanently) cultivated, i.e., corresponding to Rollet's vegetation type 15 (see Table III B-C, Part B). On the other hand, the total of permanently cultivated land that was exposed to herbicide sprays (one or more) was 261,229 acres (see same Table, Part C), and as already mentioned, there were almost no missions designated as "crop destruction" in the Delta (MR IV), which contains the main cultivated land areas of SVN.

It is thus obvious that the missions designated crop destruction are quite inadequate for obtaining a complete picture of the extent of herbicide exposure of and damage to cultivated land. They account for only about 16 percent of the permanently cultivated land area which was sprayed with herbicides; the remainder was sprayed by missions designated as defoliation. This is fully borne out by analyses of sequential photography of 18 selected study areas scattered over the entire country of SVN; in 16 of these, more crop land had been sprayed by defoliation than by crop destruction missions (see Section VII B[1]). The recorded distribution of the crop destruction missions with respect to vegetation types suggests that most of these missions were directed against small and impermanent (swidden) cultivation areas, or that there were errors in recording the intended purpose and/or location of many of these missions, or that a large proportion of the area included in the recorded target was non-agricultural land.

Most of the crop destruction missions were flown in areas which were inaccessible because of security reasons, and in which the Committee did not carry out other studies based on photo interpretation. For this reason, a limited study, using HERBS records (uncorrected) and aerial photographs, was undertaken to try to determine the pattern of these missions in space and time, and to assess their effect on vegetation, including both the crops which were the nominal targets, and surrounding non-crop areas.

Map overlays of crop destruction missions at 1:250,000 scale were plotted by using the coordinates of the mission as recorded in the uncorrected HERBS tape. These maps showed that crop destruction missions tended to occur singly or in concentrations of five to ten in relatively small areas of about 10,000 ha (25,000 acres). Seventy-two such areas were originally selected as sample areas.

The Committee had partial photographic coverage of the country corresponding to the period covered by HERBS records of crop destruction missions (August 1965 through February 1971).

To locate and observe the spray patterns on the photography, the locations of the spray missions for each sample area were transferred from the photographs to a 1:250,000 scale topographic map, by visual alignment of various topographic and cultural features on the photographs with those on the maps. The photos were then viewed stereoscopically and analyzed to determine the physical and vegetative characteristics of the areas, and to observe the spray mission patterns. A spray mission was detectable on the black and white photography as a linear strip or swath of lighter gray tone. An active agricultural field appeared light gray, in some cases nearly white, and fine-textured; an abandoned or old field appeared darker and rough-textured.

Fifteen of the 72 sample areas were between latitudes 10°45'N and 12°30'N (approximately Saigon to Ban-Me-Thuot). Of these 15 sample areas, 9 were eliminated from study because of inadequate photo coverage or because defoliation missions overlapped and were indistinguishable from or obscured the effects of crop destruction missions in the photography. The remaining six areas were subjected to detailed case studies of the pattern of crop destruction missions and their effects on vegetation, as observable on aerial photographs. The six sample areas are listed in Table IV B-5, an example of the information available for the areas in Table IV B-6.

The aerial photo analyses confirmed the pattern of single crop destruction spray coverage over a given location. This is in contrast

Table III B-5. Sample Areas Selected for Study of Crop Destruction Missions by Aerial Photo Interpretation

Area No.	MR	Province	Size (km)[a]	Center Coordinate (UTM)
1	III	Quang-Duc	10 x 10	ZU070650
2	II	Quang-Duc	15 x 3	YU530340
3	II	Lam-Dong	10 x 10	YU900050
4	II	Lam-Dong, Phuoc-Long	20 x 20	YT810870
5	II	Bin-Thuan	8 x 17	ZT240200
6	II	Bin-Thuan	10 x 12	ZS260960

a All areas are rectangular and oriented east-west (first kilometer figure) and north-south (second km figure)

Table III B-6. Sample Area 1 - Information Available

1. Crop Destruction Spray Coverage:

Date	Agent
2 October 67	Blue
3 October 67	Orange
7 October 67	Blue
21 November 68	Blue

2. Photographic Coverage:

Date	Scale
19 January 69	1:50,000
27 February 69	1:50,000
17 May 69	1:50,000

to the defoliation operations which included multiple (double, triple, or more) herbicide coverage. In some cases, a single crop destruction mission resulted in two or three parallel swaths (evidently laid down by two or three aircraft flying the same mission) which sometimes overlapped. Generally, the only other situation where multiple coverage occurred was when separate swaths intersected.

Nearly all of the crop destruction missions were oriented toward a linear series of isolated or separate fields growing along or just upslope from a stream in an upland or mountain valley. Surrounding vegetation was secondary forest or recently abandoned swidden agricultural land. The active agricultural fields along the spray path varied in size from about 0.4 to 10 ha (1 to 25 acres) and appeared to be in upland rice or other non-row grain crops. The amount of active agricultural land in the crop destruction spray paths which could be analyzed on photos represented a relatively small proportion (10 to 30 percent) of the total land area covered by these missions. The balance was in fallow swidden agriculture (30 to 40 percent) and in secondary forest which did not appear to have been recently cut (40 to 50 percent). Thus, on the basis of vegetation and spray pattern, in the few sample areas examined, only about 20 percent of the total volume of herbicide used for crop destruction missions was actually delivered onto active agricultural fields and crops.

The immediate and long-range effects of a single crop destruction mission on active agricultural fields and surrounding forest-fallow land with respect to abandonment and future use was not completely clear. In about 60 percent of the case studies, active fields appeared abandoned within one to two months after spraying and still after six to twelve months. In other cases (30 percent) sprayed fields appeared active one to three months after spraying but abandoned after six and twelve months. One observed field remained active continuously for at least twelve months. Another field abandoned after six months appeared partially reclaimed after six additional months. In two instances, sprayed forest land had been cleared for crops six months after spraying, but abandoned after six additional months.

The section on effects of the herbicide operations on settlements (VII B-1) contains additional data based on aerial photo interpretation on the effects of herbicides on crops.

For reasons suggested above, as well as limitations in the quality of the data outlined below, the results of this study of crop destruction missions cannot be projected to give a measure of the total amount of crop damage due to herbicides.

C. Review of the HERBS Tape Data; and Other Data

We may and should ask in conclusion, how comprehensive and how accurate is our inventory of herbicide use in the Vietnam war in toto, and in relation to different vegetation types? As stated before, the tabulations have been limited to the missions contained in the HERBS tape. It is therefore necessary, firstly, to review this source, and secondly, to discuss other uses of herbicides in the Vietnam war which are known but are not entered on the HERBS tape, and for which the Committee did or did not have records at its disposal.

(1) The HERBS Tape

Regarding the HERBS records, how complete and accurate is the information they contain about the herbicide operations carried out during the time period covered? Also how complete and accurate is the information itself?

Regarding the first question, the accuracy of the entries in the log book, on which the tapes are based, varied over the years, although it evidently increased by and large with time. Thus, entries for the first year (1965) show deficiencies, such as only one coordinate for a mission, which are found in later years only to a much lesser extent. Errors in transcription from log book to punch cards have undoubtedly occurred and may account at least for part of the erroneous mission records. The HERBS tape does not include any missions (defoliation and similar missions by helicopter, and herbicide operations carried out on the ground) which were authorized at the Corps (MR) level (see Section II B and Fig. II B-5). Other helicopter missions were entered only beginning June 1968.

Limitations of the data included on the HERBS tape are as follows:

1. As explained before, among 6542 missions contained in the uncorrected HERBS tape 4 had incomplete listings (all of them in the first two months of the tape), and of these, 3 had to be entirely excluded from all analyses. This is approximately 0.05 percent of all missions on the tape. In addition, as also already explained, 305 other missions or 4.6 percent were in obvious error as to the coordinates, which could not be corrected. The deficiencies in the location records for the "minor" missions (perimeter, etc.) have likewise been pointed out before. All these missions were excluded from the tabulation of the extent and frequency of spraying of different vegetation types whereas they do appear in the tabulation of total gallonage and cumulative acreage (Table III B-1).

2. The spray tank of the UC-123 airplane had a nominal capacity of 1000 gallons but the actual load was more commonly 950-980 gallons, and before 1969 was less, because of shortage of herbicide and inefficiency of the hand-pumping system used.

3. As already pointed out, the area coverage for a mission is a nominal figure, derived by multiplying the length of the spray line by 80 m swath width and by the number of aircraft. In some cases, the area given on the tape is a "target area" (see Section II B [4]) and may exceed the area actually sprayed by a considerable factor.

4. When a mission did not fly a straight line, points of change of direction were sometimes but not always given; when the mission followed a tortuous river or mountain road only the starting and end points were recorded. Other missions, especially crop destruction missions, attacked several discontinuous targets (small crop plots)--the spray being shut off between these targets--but the turn-on and turn-off points do not appear on the tape.

Despite its various shortcomings, and although the immediate source of information--the log book--was not intended for the purposes to which the information was used by the Committee; the HERBS tape is the best and in fact the only available comprehensive compilation of the major part of the herbicide operations conducted in the Vietnam war. The alternative would be to go back to the individual mission planning records and mission reports. With more than 6500 missions, and current location and even existence of all records not known, this would be quite a formidable task and considering the constraints in time and services the Committee decided against such an undertaking. A check was made of over 200 original mission reports, taken at random from different provinces and different years, and all of these were correctly included in the HERBS tape. Obviously, if the reports themselves contained errors they could not have been identified. In a number of cases, a check was made of the accuracy of individual missions, as recorded on the tape, against aerial photos, and a number of disagreements were found particularly in the case of crop destruction missions, between the coordinates in the tape (printout) and the actual mission location (see following section). The overall experience, especially that in work on damage to inland forests (Section IV B) which involved extensive photo interpretation, suggests however that the great majority of herbicide missions were located where, or close to where, the records indicate.

Strong support for the belief that, despite inaccuracies in records of individual missions, the HERBS tape is a reliable source for the inventory of the herbicide operations (as far as covered by the tape) derives from a comparison of the HERBS tape data with aerial photography for the mangrove forests of the Ca Mau Peninsula. The herbicide missions as plotted on a map of the Ca Mau area closely agree with the damaged areas plotted from aerial photography.

One uncertainty which remained unresolved concerns the swath width. The nominal swath width of fixed-wing aircraft missions has been variously reported as 80 m or 80 yards, a difference of about 10 percent. According to information from DOD, the former is the correct figure. But there still remains some ambiguity about what fraction of the herbicide fell within the intended spray swath. The "Report on 2,4,5-T" (PSAC Report, 1971) states on the one hand that 90 percent of the spray fell within two kilometers (about 1-1/4 miles) of the edge of the swath, and on the other hand that 99.9 percent fell within one kilometer of the centerline of the swath. The latter figure is quite unrealistic, and even the former is on the high side since even from spray equipment operating on the ground one can seldom recover more than 85 to 90 percent of the nominal dosage. On the other hand, as seen on aerial photographs, many missions resulted in remarkably well-defined bands of defoliation, with completely straight and sharp sides (see Fig. III B-8). Others, however, resulted in swaths well-defined and sharp on one side, but diffuse on the other ("feathering") indicating wind drift. Thus, it is evident that the distribution of the spray depended on weather conditions. The missions were to be flown only when wind velocity at the ground did not exceed certain limits (8-10 knots). However, there are frequent reports on herbicide damage due to wind drift far outside any spray mission path. Our tabulations of sprayed areas made the assumption that the swath width was 80 m per fixed-wing aircraft. This is a minimal figure which makes no allowance for dispersal of the spray beyond the nominal spray path, but we do not see how the extent of this dispersal could be quantified or even merely approximated.

(2) Limitations of the Crop Destruction Missions Inventory

There were 51 crop destruction missions in the 6 case study areas representing six percent sample of the total of 858 crop destruction missions. Of the 51 sample missions, 42 (82 percent) were not apparent in any photography studied, but nine missions (18 percent) were apparent. However, these nine spray missions with one exception were not detectable on photographs taken more than three months after spraying (5, 6, and 12 months); in the exception, the spray swath was barely detectable as a light photographic tone after 12 1/2 months. This suggests the target and surrounding non-target had generally revegetated within three to five months after a single spray application. In the case of field crops, this was most probably due to coverage of the bare agricultural land by some kind of native vegetation; in the case of native vegetation surrounding the field this was probably due to recovery of defoliated plants and/or recolonization from adjacent unsprayed vegetation.

Two missions or 22 percent of the nine detectable crop destruction missions were identified on the HERBS tape incorrectly with respect to location coordinates. The apparent swaths on the photography were parallel to but displaced about 2 km (1.2 mi.) away from the map locations plotted from end point coordinates given in the HERBS tape. In these cases, the actual swaths were generally over agricultural land while the run, as recorded, may have been over uncultivated vegetation only.

Of the 42 crop destruction missions not apparent on any photography studied, 32 were flown 14 to 50 months prior to the date of earliest photography and one was flown six months prior to photography. Most of these were probably no longer visible because of revegetation. Nine missions were flown one to three and-a-half months prior to photography. If approximately three to five months are required for vegetation to recolonize the area or (in the case of native vegetation) to recover, the fact that the latter (nine) crop destruction missions, which represented 21 percent of the 42 missions, were not apparent suggests that they were identified incorrectly on the HERBS tape. This proportion of incorrect missions is close to the 22 percent missions which could be identified on photographs but were incorrectly recorded on the tape, but as these 22 percent correspond to only two missions, this agreement cannot be given great weight. Of the other 33 of the 42 crop destruction missions not apparent on aerial photos, some may also have been incorrectly recorded as to location coordinates. Since the nine spray missions thought to be recorded incorrectly could not be located or identified elsewhere on the 1:50,000 scale photographic prints, each of which covered an area about 12 by 12 km, it appears possible that their actual locations would have been at least 6 km away from the recorded locations.

(3) Other Information on Herbicide Missions

In addition to the HERBS tape, the Committee had at its disposal the following records on herbicide missions:

(a) The "List of 202 Task Realized" covering the period between February 1962 through September 1965, based on information maintained by RVN military authorities, and compiled in 1968 in the Combat Development Center, MACV. This lists "order numbers" as "projects" (general locations, often with specific coordinates, within which herbicide application was authorized for a period of time). Area covered and gallons of agent delivered are usually reported; number and type of aircraft, purpose of mission and particularly type of agent are much less regularly reported A total of 227 "orders" is included, covering 164,857 hectares (about 410,000 acres) with 1,297,305 gallons. These figures amount to 7 percent of the area and about 7.4 percent of the gallons recorded in the uncorrected HERBS tape. No area or gallonage is given for 13 "orders."

(b) A computer printout covering the period from March 1971 through October of the same year, when herbicide use except at the MR level was terminated. The printout contains the same data as the HERBS tape and includes 31 missions with 5,371 hectares (about 13,000 acres) and 35,447 gallons. All missions were by helicopter. No Orange was used during this period; 24,727 gallons of White and 10,700 gallons of Blue were sprayed on 3 Enemy Routes, 2 Friendly Routes, 16 Perimeter of Bases, 4 Cache Sites and 6 Waterway-Landing Zones. These missions are equal to 0.2 percent of both the gallons and the area of those recorded on the uncorrected HERBS tape.

(c) Reports of herbicide "dumps" for the years 1967, 1968, and part of 1969 (through 22 April). Dump sites were points at which aircraft released the herbicide it was carrying--in many cases, the entire load of about 1000 gallons--because of problems which required an immediate reduction of its load. Under such emergency conditions the load could be dumped in one-eighth the time required for a normal spray run with the plane usually flying on a turning course. With a full load, this could result in eight times if not more the normal concentration of chemical on the ground, assuming the aircraft was operating at low altitude. Most reported dumps for which altitude was recorded were however made from high altitudes.

Of these documents, the computer printout (item No. b) has the same origin as the HERBS tape and may be assumed to have the same degree of accuracy. As it does not contain any defoliation and crop destruction missions our tabulations of these types of missions are not affected, though total gallonage and acreage of all herbicide missions are increased.

The information on dump sites is often fragmentary; entries most commonly missing are quantity and altitude, and the location is frequently vague, obviously in error, or altogether lacking.

Information on herbicide uses for military purposes in SVN which the Committee was unable to obtain, because records were incomplete or unavailable, includes the following cases:

1. Records of any herbicide missions authorized at the MR (Corps) level.

2. Records of herbicide missions carried out by the RVN Armed Forces before and after cessation of the American herbicide program.

3. Records of "dumps" outside the period 1967 to April 1969.

The first two concern helicopter missions and in addition sprays made by land and water-borne equipment, and none of them fall into the category of crop destruction missions as these required clearance both at the MR level and in Saigon.

Table III C-1 represents an attempt at estimating the total military usage of herbicides in SVN, with an explanation of the pertinent assumptions and estimates. The following additional remarks should be made:

1. Regarding item 3 in the table, the same kind of computation could obviously be made in the reciprocal manner; that is, one could project the omissions of "202 Task" list data on the HERBS tape for the entire period covered by the tape. The figure would be 800 missions. However, considering the different history and degree of internal completeness of the two documents we feel this would result in a considerable overestimate. The information in the HERBS tape has been corrected, as far as possible, in another way (see above).

Table III C-1

Records and Estimates for Quantities of Herbicides in All Herbicide Operations in the Vietnam War
(The area figures given make no allowance for multiple coverage; [NA = no information available]).

Source or estimate	Missions or Projects	Gallons Orange	Gallons White	Gallons Blue	Gallons Total	Area (Acres)
1. HERBS tape, August 1965 to February 1971 (uncorrected)						
(a) Recorded	6,542	11,261,429	5,246,502	1,124,307	17,632,238	5,709,953
(b) Estimated ("minor" missions)						(168,628)
2. Projects in "List of 202 Task Realized" not listed on HERBS tape						
(a) Recorded	195	NA	NA	NA	1,257,573	395,099
(b) Estimated (13 projects)					(11,526)	(3,517)
3. Estimated omissions from "202 Task" list by comparison with HERBS tape	(71)	NA	NA	NA	(430,765)	(135,148)
4. HERBS printouts, 1 March to 31 October 1971	31	0	24,727	10,700	35,447	13,266
5. Estimated omission of helicopter missions, HERBS tape, August 1965 to 18 June 1968	(1,710)	NA	NA	NA	(618,200)	(NA)
6. Recorded Dumps						
(a) Recorded	36	5,500	2,900	2,400	10,800	NA
(b) Estimated (23 dumps)					(19,090)	NA
7. Estimated omissions of dumps	(20)	NA	NA	NA	(16,600)	NA
8. Missions authorized at Corps (MR) level or carried out by RVN forces	NA	NA	NA	NA	NA	NA
Total Use						
Recorded		11,266,929	5,274,129	1,137,470	18,936,068	6,118,318
Estimated		NA	NA	NA	(1,096,171)	(307,293)
Total		11,266,929+	5,274,129+	1,137,470+	20,032,239+	6,425,019+

Explanations for individual items:

2.(b) - Computed from the average gallonage and area of the projects for which these data are given.

3. - Derived from a comparison of the "202 Task" list with the HERBS tape data for the period August-September 1965 (where the two sources overlap) and the average gallonage and area figures for the "202 Task" projects for which these data are available.

5. - Estimated assuming same ratio between helicopter and fixed-wing missions as of June 1968 to February 1971. Probably an overestimate as helicopter missions increased in relative frequency in the last period of herbicide operations, particularly after July 1970.

6.(b) - Estimated from the average figure (830 gallons) for the 13 dumps with this information. One "unconfirmed" dump has not been included. Three of the dumps for which location (but not the Agent) was given were made over the ocean.

7. - Assuming same proportion of dumps to total missions as in period covered by dump records, and same average gallonage.

8. - No estimates possible.

2. The "202 Task" list is very deficient on the kind of agent used. During the period of the military herbicide program in SVN covered by this list the agents used principally were Purple and Orange, the latter replacing the former; however, Agent Blue may also have been used. For the omitted dumps (item 6 of Table III C-1) it would be possible to project the use of different agents from the date on the recorded missions or dumps but for the missions authorized at the MR level and those carried out by RVN Armed Forces (item 8), no information on the agents used is available, except that the RVN Armed Forces did not have use of Agent Orange. Because of these gaps, we felt that a breakdown of the estimates by agents would involve too much guesswork, and limited ourselves to total gallonage.

Inspection of Table III C-1 shows that our inventory of herbicide operations in the Vietnam war, as given in Section III B and considering the uncorrected HERBS tape (including the estimated acreage of the "minor" missions) accounts for over 88.4 percent of the amounts of herbicide used and about 93 percent of the areas sprayed, as obtained from all available records and all estimates we were able to make. The corresponding figures for the corrected HERBS tape are 85 and 86.3 percent, respectively; the acreage figure used for tabulating extent and frequency of sprays by vegetation type (Table III B-3) and likewise for assessments of damage, particularly in the inland forests (Section IV B [3]), from both of which the uncorrected and the "minor" missions on the HERBS tape were excluded, is 83.8 percent of all records and estimates.

(4) Comparison with Procurement Records

Another approach to test the accuracy of the inventory of herbicide missions was comparison with the procurement records of DOD. This is shown in Table III C-2.

Among herbicides the use of which is accounted for, there appears to exist a "deficit" for Agent Orange, that is, more of this agent is recorded as having been sprayed than being shipped to and remaining in SVN. The amounts of Agents Blue and White sent to SVN are greater than those the use of which is accounted for, and it is known that certain quantities are still in SVN. If the estimate for all herbicides--as far as it can be made--is used, the total used considerably exceeds the total on the procurement records. Among the reasons for this may be absence of early helicopter records, difference between nominal and actual herbicide loads, and perhaps incomplete procurement records.

D. Summary

Based on the HERBS tape--a computer tape which covers herbicide operations for the period August 1965 through February 1971--a total of 17,632,000 gal. of herbicide have been sprayed in 6,539 missions during the military herbicide operations in SVN. Of these, 11,261,429 gal. and 4,109 missions were Agent Orange; 5,246,502 gal. and 1,786 missions Agent White; and 1,124,307 gal. and 640 missions Agent Blue. Of the total missions, 4,561 were defoliation and 858 crop destruction missions; the

Table III C-2

Account of Gallons of Herbicide Disposed of in Vietnam as of 18 June 1973

	Orange	White	Blue	Purple	TOTAL
1. Procured[a]	12,853,748	5,764,215	1,368,015	NA	19,985,978
(a) Not shipped to Vietnam[a]	844,580	nil	177,430	NA	1,022,010
(b) Shipped back from Vietnam[a]	1,378,740	nil	nil	NA	1,378,740
(c) Total disposed of in Vietnam	10,630,428	5,764,215	1,190,585	NA	17,585,228
2. Use Accounted for[b]	11,266,929	5,274,129	1,137,470	NA	18,966,674
(a) Estimated Use[b]	NA	NA	NA	NA	1,065,565+
(b) Total	11,266,929+	5,274,147+	1,137,470+	NA	20,032,239+
Difference 2(b) minus 1(c)	-636,501	-490,068	53,115	NA	-2,447,011

[a] Source: Office of the Director of Defense Research and Engineering, DOD, Thomas R. Dashiell, Staff Assistant for Chemical Technology, letter dated 18 June 1973.

[b] Source: Table III C-1.

NA = no information available.

remainder were flown over or around base perimeters, cache sites, communication routes, and waterways.

. After correction of 575 missions with faulty location records and elimination of 305 missions the erroneous location records of which could not be corrected, and assuming a swath width of 80 m (264 ft) per herbicide aircraft, it was determined that a total of 3,578,864 acres or 8.6 percent of SVN were sprayed in herbicide operations. Of this, 2,356,645 acres were sprayed once, 799,754 acres twice, and 422,365 acres three or more times. The time intervals between multiple sprays varied between less than one month and more than 12 months. Of the major vegetation types, 2,670,000 acres or 10.3 percent of the inland forests, excluding pine forests, were sprayed; 318,000 acres (36.1 percent) of the mangrove forests, and 260,000 acres (3 percent) of cultivated land, excluding small agricultural areas in the inland forests.

An analysis of the HERBS tape indicates that, despite certain recognized deficiencies, they are a reliable source for an assessment of the major part of the herbicide operations in SVN. Information and estimates for herbicide operations not covered by the HERBS tape may account for an additional 2,400,000 gal. (all agents) and 540,000 acres so that the HERBS tape data account for about 86 percent of all herbicide operations.

REFERENCES

Moormann, F.R., 1961. Soil map prepared in connection with "The Soils of the Republic of Vietnam."
Ministry of Agriculture, Directorate of Studies & Research in Agronomy, Forestry and Animal Husbandry, Saigon.

Rollet, Bernard, 1956. Map -- "Vegetation Map of South Vietnam, 1:1,000,000."

Executive Office of the President, Office of Science & Technology, March 1971. Report on 2,4,5-T.
A Report of the Panel on Herbicides of the President's Science Advisory Committee.
Government Printing Office, Wash., D.C.

IV. ASSESSMENT OF THE EFFECTS OF HERBICIDES ON VEGETATION IN SOUTH VIETNAM

A. Introduction

The preceding section describes the Committee's results in arriving at a quantitative determination of the extent of the herbicide operation in SVN; the quantities of the different agents that were used; and the land area, according to vegetation types that were sprayed once or repeatedly. The present section will be concerned with the Committee's attempts at determining the effects of herbicides on the native vegetation of the country.

In considering the effects of herbicides on vegetation, it needs to be clearly understood that herbicide applications can have two possible results: (1) defoliation may be transient, the plant may be caused to shed its leaves prematurely, but after a time it may produce new leaves and its growth may not be permanently affected, or (2) defoliation may be followed by the death of the plant, or part of it, resulting in a more or less severe set-back to its development, for example in the case of a tree, the partial die-back of the crown. When herbicides were used for military purposes, as in SVN, some plants received large doses and the second type of result was often seen, particularly in plants exposed to spray.

The sensitivity of different plant species to herbicides and defoliation is different; even broadleaf plants, while generally sensitive to 2,4-D, 2,4,5-T and picloram, exhibit considerable species differences in sensitivity. Thus, to accomplish complete defoliation in a forest consisting of numerous species--as tropical forests do--it is necessary to choose a dosage that will defoliate the most resistant species but this dosage will prove lethal or highly injurious to the less resistant ones. However, from the physiological and ecological viewpoint it is obviously a very different matter whether the trees in a forest or a tree crop, such as coconuts and rubber, are made to lose their leaves but remain capable of continued development, or whether part of the trees are killed or their growth retarded.

It was explained that the military authorities distinguished two main objectives of the herbicide operations in SVN: defoliation and crop destruction. These two types of missions differed in certain respects; namely, in the geographic distribution over the country as a whole, the degree of concentration in a given target area, and the relative quantities of some of the agents used (see Section III C-5 and C-6). On the other hand--as was already said or implied--when one uses the physiological and ecological viewpoint the similarities between the two types of herbicide missions become much greater than their dissimilarities. While there were differences in the relative amounts, the same agents (Orange, White, and Blue) were used for both defoliation and crop destruction missions. Crops were destroyed or damaged by operations designated as defoliation. In part this was because herbicide was directly sprayed on crops, in part because of drift of the herbicide outside the target area. It was already mentioned that although, this result cannot be generalized because the study areas were not selected at random, in 16 out of 18 areas studied by means of aerial photography, crop damage by defoliation missions was greater, sometimes considerably so, than by crop destruction missions (see Section VII B-6; details in Section VII B-1).[a] On the other hand, crop destruction operations resulted in herbicide deposition also on native vegetation surrounding the crop which was the target of the mission. A sample of crop destruction missions, analyzed, again by means of aerial photography, indicated that in fact only one-fifth of the herbicide used in these missions was deposited on crops whereas the rest impinged on the surrounding native vegetation, mostly inland forest (see Section III B [6]). Thus, in the analysis of physiological and ecological effects of herbicides, as used in the Vietnam war, it is neither possible nor appropriate to differentiate between defoliation and crop destruction missions.

From the inventory of the herbicide operations (Section III) it is evident that two types of native vegetation in SVN have been the main targets of herbicide sprays, namely, the inland and the mangrove forests, the latter including the Melaleuca woodlands. The distribution of these vegetation types is shown in the map of Major Vegetation Types in the Map Section and their characteristics are briefly described in Section II E. The inland forests occupy 63 percent of the area of SVN and can be composed of many species of deciduous and evergreen broad-leaved trees, shrubs, bamboo, and ground vegetation; however, the types of forest and their condition vary greatly, including large areas occupied by bamboo, and others which contain only a few large trees. A small portion of the inland forests

---

[a]This statement is not intended as an expression of opinion as to whether or not the official policy on herbicide operations was violated. According to this policy crops were not to be sprayed, and herbicide missions not to be flown near crops, unless these offered shelter to hostile forces (e.g., along roads or waterways) or if they were in areas under enemy control or where the population was considered as unreliable. It was not within the Committee's charge, and would besides have required considerable additional effort, to determine whether, if crops were sprayed or a mission flown over or near a settlement, those premises were existent. Our aim was to determine the effects on people and plants.

(about one percent of the land area) are pine forests; these are not considered here as they were exposed to only little herbicide spraying and we conducted no studies in this forest type. The mangrove forests account for about 1.7 percent of the area of SVN and consist of relatively few species of trees and undergrowth. The Melaleuca woodlands were also subjected to heavy herbicide spraying, but as we were unable to make any field studies of this vegetation type, which account for about 1 percent of the area of SVN, no analysis of the damage was attempted.

A study of the effects of the herbicide operations on inland forests was centered in the Terrace Region north and northwest of Saigon, in the areas formerly designated as War Zones C and D. This area was chosen for study because of several reasons. Intensive and extensive herbicide operations had been conducted there since February 1962 in several forest types; 60 percent of the inland forest area that was sprayed is found in this region. The area was accessible for aerial observation, and seemed at least potentially accessible for on-site investigation from the ground. Security problems precluded any extensive, quantitative on-site studies, however.

Investigation of the mangrove forests was centered in the Rung Sat Special Zone southeast of Saigon which surrounds the main shipping channel from the South China Sea into Saigon. The area was chosen because a large block of about 230 square miles (about 600 km^2) had been sprayed, much of it many times; thus the ecologic effect was expected to be greater than in any other mangrove area. Furthermore, the area was easily accessible for aerial observations, and was sufficiently secure to permit a number of on-site investigations of different kinds (damage of vegetation, effects on estuarine animal life, effects on soil, response of people).

Crop damage has occurred in all parts of the country. The problems of assessing it in any quantitative manner are, however, quite different from those of assessing damage to forests. Some of these problems have been discussed in connection with the inventory of crop destruction missions in Section III B-6. Another obvious problem is that most crops are annual plants which are planted and harvested within one growing season. A direct, quantitative assessment of crop damage could therefore have been only made immediately and on the spot, i.e., by assessing the damage after any herbicide operation that caused such damage. No such systematic assessment was made by the Committee, and in the case of missions which were flown in territory under the control of unfriendly forces it would have been impossible to do, while the Committee's work did not start until the herbicide operations, at least those under American control, had been terminated for about one year. A more indirect approach would be analysis of aerial photography to determine the areas where crop damage had occurred; combined with figures for average yields this would permit some estimate of the losses. This approach would not be as easy as it may sound because "average yields" even for the same crop may be quite different in different areas. This is particularly true of agriculture in the Highlands where a large part of the crop destruction missions were flown, because the agricultural practices vary widely not only from one ethnic group to the other, but also from village to village, and even within one village. What made this approach entirely unfeasible, however, was that photographic coverage proved inadequate as explained before. An analysis of available aerial photography for six study areas showed that the effects of crop destruction missions became nondiscernible on the photographs usually within three to five months (see Section III C-2) while the closest photographic coverage for more than half of the missions analyzed was taken 14 to 50 months after the mission. Other information on crop damage by herbicide operations was obtained by examination of pertinent documents, the photo-interpretation studies of the effect of herbicide operations on settlements in 18 selected study areas and in interviews with Vietnamese farmers and officials in some selected parts of the country. Some of the results thus obtained will be discussed in Sections VII B and VII C of the report, but they cannot be extrapolated for the nation as a whole.

B. Inland Forests

(1) General Successional Trends

An important task of the Committee was to try to assess successional trends in the inland forests damaged by military defoliation. Broad-leaved forests of the Closed and Open types have many kinds of valuable hardwood timber, and for this and other reasons are an important part of the nation's natural resources. When natural vegetation is disturbed, it may rapidly return to its original condition, or may be changed but gradually go back to that condition, or may be more or less permanently converted into another type of vegetation. The actual response will depend partly on the extent and nature of the disturbance, and partly on the type of the affected vegetation itself. It is clearly of the greatest importance to find out what kind of successional changes are taking place in the defoliated forests, what are the chances of their recovery, and what are the likely long-term effects of defoliation on the ecology and productivity of the forests. A difficulty in assessing such effects is that, although many statements have been made about the probable long-term effects of herbicides on successional trends in the forests of SVN, there is little previous experimental work on the results of herbicide applications on successions in forest areas anywhere in the tropics. The problem is further aggravated by the lack of an inventory of the South Vietnamese inland forests; this deficiency would have made accurate, quantitative work difficult even if it had not been for the other, major limitation--lack of security--under which the work had to be conducted.

Present Condition of Herbicide Sprayed Inland Forests

At the outset it is important to realize that, even though there has been widespread and serious damage, there seem to be no parts of the inland forest in which herbicide spraying by itself had led to complete destruction of vegetation over large areas such as has occurred in the mangrove forests (next section). During helicopter flights in October 1971 from Saigon to Dong Xoai in Phuoc Long Province (War Zone D), some 60 miles to the northeast, members of the Committee saw extensive areas of Closed forest in which virtually all the larger and taller ("emergent") trees appeared to be dead, presumably as a result of spraying, but everywhere beneath the dead, standing trees there was a dense mass of green, seemingly healthy vegetation, consisting of smaller trees, bamboos, and other plants. The only bare or completely devastated areas seen on these flights were bordering roads and on the perimeter of towns, villages, and military posts where the vegetation had presumably been removed by Rome plowing or some other means.

Evidence from air photographs and other sources shows that conditions in the Saigon-Dong Xoai area are typical of much of the defoliated inland forest in SVN. The earlier observations of Flamm (1968, 1970), Tschirley (1969) and others seemed to suggest that the damage due to a single spraying was probably transient and might be assumed to have no lasting consequences for the vegetation, but where, as in many areas, the forest had been sprayed repeatedly, many or all of the emergent trees die, though leaving the lower stories of the forest apparently more or less intact. Later studies of air photographs (Section IV B [3]) confirm these conclusions on the whole. However, some photographs of heavily sprayed areas show that the undergrowth has been seriously damaged or even entirely killed. Whether this is due solely to the effects of herbicides or whether fire and other factors may have played a part cannot be decided in the absence of studies on the ground.

In many places in SVN, the emergent trees have been felled and removed after being killed and much of the surviving undergrowth has been destroyed in the process. In addition, in some places the forests have been extensively damaged by fire after killing of the large trees by herbicides. (Figs. IV B-1 and B-2)

Previous Studies

Many statements have been published about the successional trends in the forests of SVN and the probable long-term effects of defoliation. Unfortunately most of them are based on fragmentary observations and much speculation, but little scientific evidence. It has, for instance, been repeatedly said or implied that the badly damaged areas have already been invaded by bamboos: the AAAS Report (Meselson et al., 1970) concluded that this "will retard the re-establishment of forest trees at least for many decades." According to Westing (1971, and similarly in other papers) "particularly in areas sprayed more than once, the overstory destruction is sufficient to permit the invasion of certain tenacious pioneer grasses." Such grasses include *Imperata cylindrica* (tranh), a coarse tufted species of little value except for thatching, as well as bamboos of various kinds (which are botanically a group of grasses). The spread of *Imperata* as a result of military defoliation, Westing (1971) believes, will lead to the forest being replaced by "semi-permanent savannas," and bamboos may form dense thickets which "may remain in place for decades." Another effect of defoliation which Westing and others think may delay the recovery of the forest for many years is the sudden release of plant nutrients or "nutrient dumping." The leaves, bark, and wood of trees that are killed contain nutrient elements. It is well known that certain tropical forest soils tend to be relatively poor in nutrients, and that a considerable fraction of the total nutrient stock is held in the living vegetation (see Section V B). Defoliation may thus lead to a rapid loss of nutrients as the dead vegetation decomposes and is washed away by the rain. It has been suggested that the resulting loss of soil fertility may have important effects on successional trends, preventing or delaying the reestablishment of trees and encouraging their replacement by grasses and other types of plants with smaller nutrient requirements.

Fig. IV B-1. Forest in Tay Ninh Province sprayed three times and not burned. Photo taken by Dr. Michael Newton in March 1972.

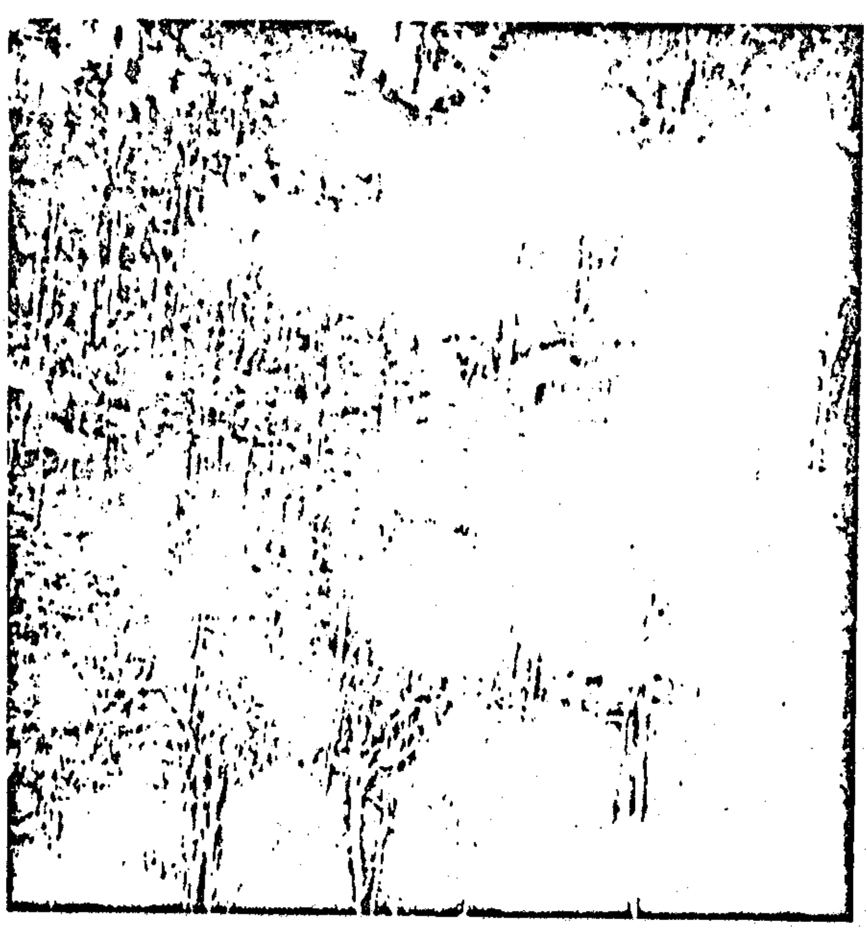


Fig. IV B-2. Badly damaged forest in Tay Ninh Province sprayed three times and burned. Photo taken by Dr. Michael Newton in March 1972.

To test such statements scientifically would require long continued systematic observations--a formidable undertaking even in a country not at war. Westing, as he admits (1971), based his report on the inland forests on "a minimum of hard data" because "essentially none of the 2 million hectares (4.9 million acres) or more of sprayed jungle is safely accessible to us."

The Status of the Inland Forests of SVN

The security situation, which made ground studies of successional changes practically impossible for Westing and other previous investigators, had not improved in 1971-72 when the Committee was in SVN. Some very brief visits to forests in War Zones C and D were made, but the small amount of relevant information obtained added only a little to the earlier observations of Flamm and Tschirley. The only other information on successional trends available to the Committee is derived from air photography and from analogies with what is known of successions in Thailand and other countries where the climate, soils, and vegetation are more or less similar to those in SVN. On this far from satisfactory basis we must attempt to give whatever assessment is possible of the short-term and long-term successional trends.

Before doing this it is necessary to put the changes due to defoliation in perspective by noting that long before the military defoliation program began, changes due to other causes had been operating in the forests of SVN, as in all but the least populated parts of the tropics.

It has sometimes been said or implied that a large proportion of the inland forest of SVN that has been sprayed with herbicides was primary or virgin forest, i.e., that they had never been farmed, logged, burned, or otherwise seriously disturbed by man, but it is unlikely that this was true even in the 1950's. Rollet (1962), one of the leading authorities on the forests of SVN, has shown that a very large part of the forest must have been affected by shifting cultivation. It certainly seems probable that much of the inland forests, except perhaps in the more remote and mountainous districts, had been more or less profoundly disturbed by human activities when the defoliation program began. The degree of disturbance varied: a large part had been much affected, another part, possibly one-third of the whole area, was classified by Rollet as "dense forest," in which disturbance was relatively slight.

Disturbance has taken many forms, ranging from the collection of brushwood to make charcoal and the culling of occasional highly prized hardwood trees, to systematic timber exploitation and clear-cutting of extensive areas to make room for rubber plantations, oil palms, and other export crops. In SVN, as in most parts of the humid tropics, swidden agriculture has affected a greater total area than any other kind of disturbance (Figs. IV B-3 and B-4). Before the escalation of the war the Montagnard peoples lived scattered through much of the forest and raised crops in small clearings. Traces of their fields or "ray" can be seen in many places on aerial photographs of the inland forests, in addition to much larger areas of secondary forest and brush around towns and permanent villages.

In swidden farming the land is usually cropped for only one or two successive seasons. It is then left to fallow and a tangle of young trees, shrubs, vines, and other plants, often including bamboos, grow up. If left undisturbed, this tangle develops in a few years into a secondary forest, different in many ways from the primary (or climax) forest that may have occupied the site before it was cleared. Secondary forest species grow faster and are shorter-lived than those of the primary forest. Even more important is the fact that the majority of the secondary forest trees cannot reproduce themselves in shade, while most primary forest species are shade-tolerant, at least when young. After a period of time--measured in decades and possibly in centuries--an undisturbed secondary forest becomes more and more similar to a primary forest. But if it is clear-cut again after a few years, or is otherwise badly disturbed, secondary forest is increasingly liable to invasion by bamboos, Imperata, and other grasses. Bamboos and grasses are important for the future succession in two ways: (1) they tend to form dense thickets that impede the establishment of young forest trees, and (2) the thickets become dry and inflammable in the dry season. Once an area has been burned, fires are liable to recur and more and more invasion by grasses and bamboos takes place. It is in this way, according to Rollet (1962), that large areas of Closed forest in SVN were converted to Open forests with grassy undergrowth, and to more or less unproductive savannas. In such areas Closed forest may return, but only if fires are controlled and trees given a chance to establish themselves. One effect of the war has been that Montagnards and other refugees were concentrated in certain areas, such as Dak To in Kontum Province (G. Hickey, personal communication). This has led to large, contiguous areas of forest being cleared and re-cleared for swiddens, in which, if forest seed sources are destroyed and recultivation occurs too soon, trees will no doubt be replaced by bamboos or grassland.

That much of the sprayed forests in SVN is secondary is of great importance in assessing their future prospects. A mosaic of secondary forests of all ages, such as probably existed when the defoliation program was begun, must have contained numerous "nuclei" of light-demanding species such as bamboos and grasses scattered througout the forest, in some places recently established on old swiddens and other clearings, elsewhere growing in association with forest species that, if the natural succession had run its course, would eventually have suppressed them.

Fig. IV B-3. Montagnard swidden agriculture in Phuoc Long Province, north of Dong-Xoai. Photo taken by Dr. Philip Ross on October 17, 1971.

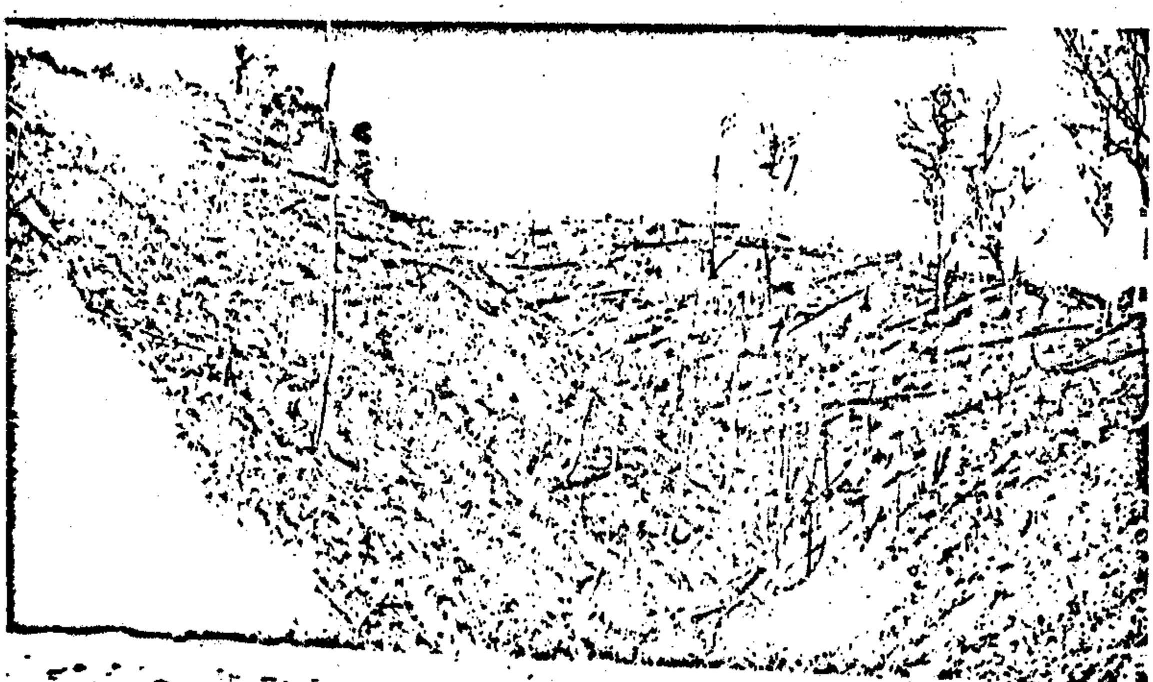


Fig. IV B-4. Field cleared by the Montagnards in Lam Dong Province. Photo taken by Prof. Geoffrey Blackman in January 1972.

The Effects of Herbicides

On this complex vegetation pattern the effects of herbicides have been superimposed. In a mature Closed forest in which emergent trees have been killed, the most important environmental change is the increased amount of light reaching the lower stories, though there will be other microclimatic effects and a decrease in root competition. Under these conditions, if an adequate number of saplings and young trees of emergent species have survived, the death of the large trees may encourage them to grow rapidly; the top story of the forest will then be soon replaced--perhaps sooner than it would have been under normal conditions. Of course, if the young as well as the older individuals have died, the emergent species will disappear and the forest will change drastically in composition or the trees may even become replaced by bamboos or grasses.

In other areas in which there is a larger proportion of light-demanding (or shade-intolerant) species, as in Open forests with a ground layer of grasses, and Closed forests at an early stage in succession with much bamboo in the undergrowth, defoliation would have quite different results. In these cases the death of the older trees would probably encourage the growth of bamboos, grasses, and other shade-intolerant species and might also lead to their spread, e.g., by increasing the number as well as the size of the bamboo clumps. This might lead to the suppression of any surviving young trees and the formation of extensive bamboo thickets, as Westing and others suppose. Such thickets are not necessarily permanent and the normal trend towards the climax may be resumed, although it could be delayed for a long time, perhaps for many decades.

What has been said in the foregoing paragraphs is a statement _of what might be expected to take place_, judging from what is known about forest succession in Southeast Asia and elsewhere, and considered in relation to our general knowledge of the situation in the forests of SVN. But to know whether this is actually happening, and to give a reliable forecast of future successional trends, the information needed is not available or at best very scanty. For instance, does the dense vegetation now occupying heavily sprayed sites in the Closed forest (as in parts of War Zone D) contain a sufficient number of saplings and young trees of emergent tree species such as members of Dipterocarpaceae? Has the removal of the emergent canopy in such forests merely revealed a preexisting understory of bamboos, or can it be demonstrated from air photographs and other evidence that the area within the forest occupied by bamboo thickets, _Imperata_, etc., has significantly increased since defoliation began? If so, is it certain that this is due to the effects of herbicides alone or have other factors such as uncontrolled logging and burning also contributed?

Regeneration in Herbicide Sprayed Inland Forests

The earliest observations on tree regeneration in defoliated SVN forests are those of Barry R. Flamm, who in company with F. H. Tschirley, visited War Zone C (Tay Ninh and Binh Long Provinces) in March 1968. Flamm (1968, 1970) noted carefully the damage to mature trees and the effect of herbicides on the regeneration (seedlings and saplings) in the sample plots of defoliated forest. The results may be summarized as follows:

Site	Type of Forest	Herbicide Treatment	Effect on Regeneration
1. Thien Ngon (4 plots)	Moist Semi-deciduous	Once sprayed (Orange, December 1966)	3 out of 4 plots adequately stocked
2. Katum (2 plots)	Moist Semi-deciduous	Twice sprayed (White, November 1966; Orange, September 1967)	Reproduction on both plots dead
3. Tong Le Chon (2 plots)	*Lagerstroemia* type	Plot 1, once sprayed (White, November 1966)	Seedlings of *Lagerstroemia* plentiful
	Moist Semi-deciduous	Plot 2, once sprayed (Orange, November 1967)	Seedlings of *Hopea odorata* plentiful, 2 plants of *Tarrietia cochinchinensis*

To this information the Committee can add the following:

(1) Several members accompanied by a Vietnamese expert on forest trees visited Cau Muoi Mot, about 8 miles (13 km) northeast of Dong-Xoai on the Dong Xoai-Bu Dang Road, on October 16, 1971. The area examined, which was sprayed with White in 1968 and with Orange in early 1969, was a mixture of low secondary growth and dense bamboo thickets with a few surviving tall trees, mainly *Irvingia malayana*, a species which seems to be not very sensitive to herbicides. The site had evidently been cleared and cultivated in the not very distant past. Aerial photographs taken in 1958 (WWS Project 166) show that it looked much the same at that date as it did in 1971, although some trees may have been killed in the interval. The Vietnamese forester, searching the very small area that could be safely explored, found a fair number of living saplings of large forest tree species including *Irvingia malayana*, numerous (99) individuals of *Sterculia alata*, and one specimen (6 ft high = 1.8 m) of the Dipterocarp *Shorea vulgaris*.

(2) In March 1972 several Committee members examined areas near Hung Dao camp, near Tay Ninh, which had been sprayed with Agent Orange in 1966, 1967 and 1968, and subsequently logged. A number of young Dipterocarps 33 to 40 ft (10 to 12 m) high were seen. A local woodman said that there were "not as many Dipterocarp seedlings and juveniles present in the understory as would be expected in an undisturbed forest or in a forest that had been logged but not sprayed." Committee members who observed this site uniformly agreed that three herbicide applications had not of themselves caused sufficient damage to permit invasion and occupation of the site by bamboo.

Concluding Remarks

From the scraps of information given above it is clearly not possible to draw scientifically valid conclusions. One can only suggest that: (1) even in forest areas that have been sprayed more than once young individuals of the taller forest trees may survive, possibly in large enough numbers for the forest to recover eventually if protected from further disturbance; (2) in other areas not enough young individuals survive to ensure recovery within a reasonable period of time. The difference in the amount of surviving regeneration in different areas could depend on many factors, such as conditions at the time of spraying and whether defoliation was followed by burning or logging; and (3) the differing susceptibility of tree species to herbicides may lead to changes in the composition of the forest.

Because of the great economic potential of the inland forest of SVN, in the post-war period of reconstruction it may well be decided to undertake a large-scale project of forest rehabilitation. If such a program is adopted, the following considerations should be borne in mind:

1. It seems probable that all single-sprayed and most multiple-sprayed forest areas could eventually be restored to productive forestry if an appropriate silvicultural policy is adopted.

2. In some areas, especially where there has been only one herbicide application, the forest may recover naturally, provided it can be protected from swidden, logging, and other disturbances.

3. Before any program of forest protection and restoration can be planned, systematic studies of the sprayed areas are essential, with special attention to the numbers and sizes of young individuals of the important tree species.

The possible effects on the nutrient balance of forest soils will be considered in a later section (V B). They may be one among many factors controlling the course and rate of succession but are likely to be of importance only in already nutrient-depleted soils.

(2) Bamboo in Relation to Defoliation of Inland Forests

The principal objective of this study was to find out whether bamboos had replaced broad-leaved trees in the inland forests as a result of spraying with herbicides, and if so, on how large a scale. Concern that bamboo is invading and replacing forests has been voiced by several authors (Meselson et al., 1970; Tschirley, 1969; Westing, 1970). Our work was centered primarily in some of the forests of the Terrace Region (Section II E) because they contain a greater amount of commercially valuable timber than do the Open forest.

Little field work was possible because of security conditions, but limited observations were made along the highways to the Col de Blao (Route #20, Lam-Dong Province), An-Loc (Route #13, Binh-Long Province), Tay-Ninh City (Tay-Ninh Province), and Trang-Bom to Xuan-Loc (Route #1, Long-Khanh Province). Brief ground observations were also made of a sprayed forest with bamboos near Cau Muoi-Mot, and an unsprayed forest near Dong-Xoai, about 8 miles (12.8 km) southwest (see Section IV B-1). Because of the limited opportunity for on-site investigation, assessment of the role played by bamboos in the ecology of forests sprayed with herbicides can only be regarded as tentative. The ground observations were supplemented with three helicopter trips over War Zones C and D.

Areas with Dominant Bamboo Coverage

Bamboos were already present prior to the military use of herbicides in many types of forests in Vietnam. In secondary forests they became dominant over considerable areas where they are said to persist for many years. These "bambusaies" were mapped by Rollet (1956), using 1952-53 aerial photography, as a distinct vegetation type.

In the lowland secondary forest, bamboos were scattered about in the understory, especially on schistose slopes and red soils (Rollet, 1962). Bamboos on such soils can frequently colonize an area relatively rapidly. It was also noted by Rollet (1962a) that there is generally an understory of bamboos (Oxytenanthera sp.) in the Open forests. In the highlands, at a medium elevation of 1800 to 3800 ft. (540 to 1150 m), Rollet noted extensive stands of bamboos in the secondary forest.

All told, prior to the application of herbicides for military purposes in SVN, there were an estimated 1.4 million acres on which bamboos were already well established as dominant species.[a]

---

[a] Estimated by Committee from a Vegetation Map of SVN which was prepared by the National Geographic Service in Dalat in 1969. The Map seems to be based on Rollet's 1956 map, but it shows "Bambusaies" as a separate type.

Specific Bamboos in Closed Forest Ecosystems

In the dense forest, Bambusa species may form rather large, pure populations on specific sites such as borders of streams, and especially the slopes adjacent to them (Barry et al., 1960). In the secondary forest arising from swiddens, bamboo generally appears in 10 to 15 years, and in 20 years has developed into a "sea of bamboo" which is said to persist for a century or more (Barry et al., 1960).

Further observations on the species of bamboos found in SVN were made by Schmid on a trip via Highway #20 to Dalat on December 21-24, 1953, with F. A. McClure (Schmid, 1953). According to this report, the populations of large, spiny bamboos growing in large clumps to about 25 ft (7.5 m) in height, or forming indeterminate thickets relatively low in height, occur at elevations of 150 to 300 ft (45 to 90 m) on old alluvial soils. There are two main types of such bamboos recognized by Rollet: (1) Bambusa sp. with low stature, bushy indeterminate clumps such as found around the Forestry Station at Trang-Bom; and (2) Bambusa blumeana on relatively rich soils, forming large clumps, well-delineated, with stems up to 75 ft (22.5 m) tall.

On soils derived from schists or granites, especially on slopes between 2100 and 2400 ft (630 to 720 m), Lingnania sp. was found. Species of Oxytenanthera (O. dinhensis, the most common; and O. densa) were noted in Montagnard swiddens. Other genera and species of bamboos were found by the authors on this brief trip, but with the exception of the climbing bamboo at elevations around 4500 ft (1350 m), none appear to be common in the dense and secondary Closed forest ecosystem.

On the other hand, Ho (personal communication) recognized two ecological types of common bamboos from the An-Loc--Tay-Ninh region: (1) Bambusa arundinacea, a large spiny species usually found on slopes 300 to 600 ft (90 to 180 m) or more away from streams, but at An-Loc apparently far from water courses; and (2) Oxytenanthera, species of which occupy dry soils.

Finally it is appropriate to emphasize that the identification of bamboo species is rather difficult. In SVN it is obvious from the writings of Vietnamese and French botanists of the past 20 years that much work remains to be done before a complete and authoritative account of the species of bamboos can be published for that country.

Our observations do not permit firm conclusions, but do suggest that at least where only one or two applications of herbicides were made, there are prospects for regrowth of a mature forest composed of many of the dominant species, despite the presence of abundant bamboos.

To such a statement should be added the proviso that fires, particularly during the dry season, could probably destroy the young saplings and thus serve to perpetuate an understory composed mainly of bamboos. Such fires, burning unchecked, were observed by all Committee members who made overflights during the dry season (Fig. IV B-6). The fires were especially common in severely degraded forest areas many of which appear to have supported only bamboos (or bamboos and grasses) prior to 1960.

The Reproduction of the Bamboos Common to Closed Forest Areas

According to McClure (1967), "The incidence of maturation of fruits is relatively low in the majority of known bamboos ... abundant yields occur in only a relatively few species out of the hundred that have been observed in flower." If such statements are applicable to common bamboos in SVN, then one would not expect a high frequency of seed production. Indeed, on the basis of what data we have obtained from direct field study in SVN and the published information from a lifetime of investigations of bamboos by McClure (1967), it is reasonable to conclude that rapid colonization by bamboos of cleared forest is not usually accomplished in SVN by production of abundant seeds and seedlings. Thus, spread of bamboos, when it occurs, is more likely to be by vegetative means. According to the Assistant Chief Forester at the Forestry Station at Trang-Bom, the population of bamboos increases substantially following clearing operations which leave behind numerous cut-up sections of underground parts capable of sprouting. Moreover, apparently alterations of the Closed forest, as by extensive logging operations or killing of the upper canopy species by herbicides, will produce ecological conditions favoring the rapid formation of new culms of certain bamboos (Huberman, 1959). For this reason, when sites with an understory of Bambusa arundinacea and species of Oxytenanthera, as described by Boulbet (1960), are converted by the Montagnards into swidden (ray), the bamboos will soon occupy the site upon cessation of cropping and will persist for a long time (Rollet, 1962a).

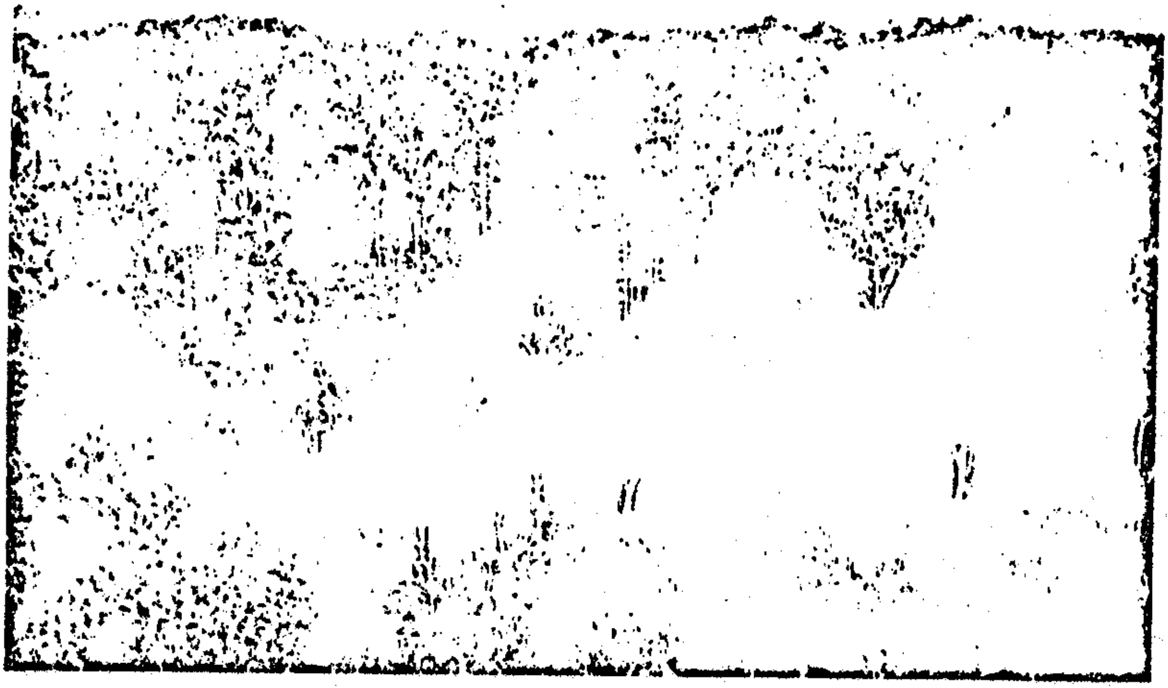


Fig. IV B-5. Secondary forest near Cau Muoi-Mot sprayed December 1968 showing bamboos. Photo taken by Dr. Philip Ross on October 17, 1971.

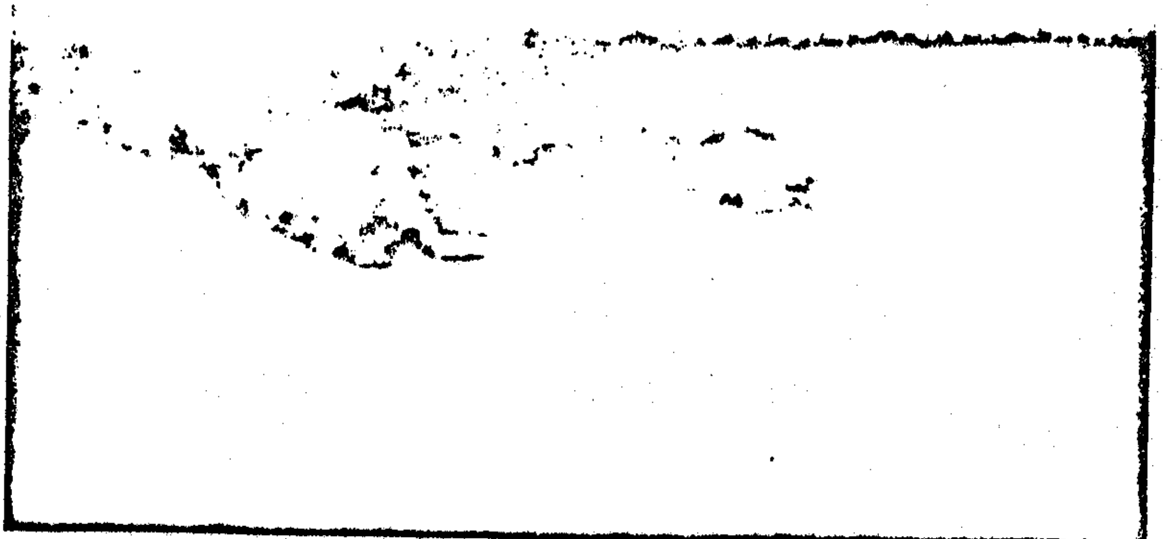


Fig. IV B-6. Fires in a damaged forest in Tay Ninh Province. Photo taken by Dr. Michael Newton in March 1972.

Economic Value of Bamboos

Much research has been carried out in the silviculture of useful bamboos in various countries, especially in Asia (Huberman, 1959). Moreover, the economic value of many of these bamboos is very significant in tropical Asia, as noted by FAO Report (1961), McClure (1966), and McKinley (1957), among many others.

McKinley (1957) lists the main species and uses of bamboos in SVN. Included among these principal species are two or three which are significantly involved in colonizing cleared-burned and probably also heavily defoliated Closed forest areas: (1) Bambusa blumeana has wide distribution in South Vietnam, and it is also considered by McKinley as the most useful bamboo for many purposes. (2) Bambusa arundinacea is listed by McKinley as useful for construction purposes, and as a source of edible shoots. Ho (personal communication) regards this species, rather than B. blumeana, as the most widespread in SVN, as well as the most useful for various purposes. As suggested by Ho (personal communication) another bamboo from the Closed forest, which is frequently used for construction of articles, such as furniture, poles, fences, etc., is Schizostachyum zollingeri, known as Lo-o.

McKinley (1957) states that the bamboos useful for paper pulp develop rather thin-walled stems, but there is no published information suggesting that such bamboos are involved with the successional patterns in Closed forest following severe disturbances. On the other hand, McKinley (1957) notes that near Tay-Ninh there has been a paper factory utilizing bamboo shoots of about six months of age for manufacturing a kind of blotting paper. Neither scientific nor common names were given for the bamboo thus utilized. Moreover, no specific information on uses of species of Oxytenanthera were noted by McKinley. Yet these bamboos are among the important species common in Closed forest lands which have been cleared or severely defoliated by herbicides.

Conclusions

(1) As a result of centuries of fire and swidden agriculture in SVN, extensive areas support pure or mixed stands of bamboos which existed prior to the application of herbicides for military purposes.

(2) Evidence from published field studies of the Closed forest indicates that several bamboos may grow as natural components of the dense and the secondary forest; but they are by no means invariably present.

(3) After clear-cutting or extensive logging, the forest canopy is open so that altered ecological conditions favor an increase in the

population of the sub-dominant bamboos. Increase by vegetative means occurs in abandoned swidden and after forest clearing operations and can be relatively rapid. Spread of bamboos by seed appears to be rather infrequent in SVN, and rapid invasion of new areas was not observed.

(4) Information derived from limited field and aerial reconnaissance of Closed forests in War Zones C and D north of Saigon suggests that where defoliation has led to death of the trees of the upper and second stories, with suppression of their reproduction, bamboos, if present in the area, will tend to increase with establishment of pure stands which may persist for many years. Regrowth of young plants of the original forest trees can be prevented by seasonal fires.

(3) Quantitative Assessment of Herbicide Damage to the Inland Forest

Introduction

The objective of the Inland Forest Study was to assess the effects of the herbicide upon the inland forests of SVN. Damage to forests can take different forms: (a) loss of merchantable timber, (b) loss of growing stock, (c) loss of growth, (d) loss of seed source, (e) loss of non-merchantable timber. The Committee evaluated herbicide effects in terms of loss of merchantable timber as its first priority. Within certain margins of error this loss category could be assessed with quantitative methods widely used in forest inventory, making use of extensive aerial photographic coverage of SVN. Data from comparable countries were also used because opportunities for inspection of the SVN forests on the ground were very limited (Section I B [3]). Evaluation of loss of merchantable timber was thought to be important, too, because earlier reports on the effect of the herbicide operations had suggested that these had resulted in very large, direct economic losses. It has also been suggested that post-war recovery of SVN will require large quantities of forest products for domestic use, and that the forest resources of SVN provide an important exportable commodity which can generate the capital required for recovery and development after hostilities have ceased.

In the course of the study of the inland forests the Committee had occasion to evaluate some of the assumptions basic to the earlier studies. As will be discussed later in this chapter, several of them were found by us to be seriously in error, particularly those on the average merchantable volume of the inland forests of SVN, and on the average non-salvaged loss of merchantable timber in forest areas subjected to one and to more than one herbicide spray, resulting in a very large overestimate of herbicide damage to merchantable timber.

However, while it was deemed important to undertake a quantitative estimate of herbicide damage in terms of "loss of merchantable timber," it should not be inferred from our efforts in this domain that all, or even most of the damage to the inland forests due to war impact generally, and herbicide impact specifically is encompassed in this category. In fact, as will also be discussed later in this chapter, it may well prove that other forms of forest damage and other war impacts caused much more substantial damage both to standing timber and to long-term forest productivity. Under the conditions of this study, it was not possible to assess these forms of damage with a similar degree of precision, but estimates of losses of non-merchantable timber will be given later.

Herbicides were sprayed over large areas of inland forest during the years 1962 to 1971; the heaviest herbicide operations were conducted between 1967 and 1969. During and after the period of herbicide spraying, the forest areas were also subjected to other military actions such as bombing, shelling, and land clearing to reduce ambush danger along highways. In addition, the forests continued to be harvested for timber and fuelwood and cut and burned to provide agricultural clearings (swidden). These harvestings and agricultural activities have been applied to the forests of SVN for centuries, although the recent military operations have modified them to a varying degree in location and intensity.

To obtain a quick impression of the scale of these activities, the reader is referred to the maps in Figs. IV B-7, IV B-8, and IV B-9, which for a sample area of intense military action illustrate the forest cover and the pattern of herbicide spray missions for 1965-1970. The overlap of these activities can be judged from these figures. Within areas sprayed with herbicides it is difficult to tell from aerial photos taken in 1972-1973 whether dead trees had been killed by herbicides, bombing, shelling, or were the result of normal mortality. Where there was evidence of recent harvesting it was not possible to determine whether trees harvested were cut and removed after being killed by herbicide or other war impact, had died from natural mortality, or were cut as living trees in normal harvesting. For the purpose of this study it was assumed that trees that were cut and removed were utilizable and that they therefore did not constitute loss regardless of their status at the time of cutting. As a part of the assessment of herbicide damage, a study was made to evaluate the level of normal mortality in forests that were treated. The problem of separating the effects of herbicides from other effects was a continual source of difficulty in this study.

The intended effect of military spraying of herbicides was to remove the leaves from the trees, making enemy troops and the trails, arms caches, etc. used by them visible from the air. The effect of single or repeated herbicide spraying on an individual tree is very variable and seems to depend on several factors, including the species of the tree, its physiological state, and the weather conditions during and after spraying. Some trees are apparently unaffected, some lose their leaves but later recover more or less completely, some are killed. Even when a tree survives defoliation the new crop of leaves may be abnormal and die-back of a larger or smaller part of the crown is common.

Some 2.7 million acres (1.1 million hectares [ha]) of the inland forest were sprayed in the defoliation missions and crop destruction missions flown between August 1965 and February 1970 and recorded on the HERBS tape. It was, therefore, not feasible to obtain and examine aerial photographs of the whole sprayed area. The tree mortality assessment was made on samples representing 9 percent of the inland forest area of Military Region III. In addition to the defoliation and crop destruction mission, the HERBS tape contains records of missions flown in the vicinity of fortified bases and supply lines, and herbicide operations were carried out before August 1965 and after February 1970. Some of these missions undoubtedly affected inland forest areas, but the exact area is not known in every case. They had thus to be excluded from our analysis (compare Section III C-3). These missions amount to about 15-17 percent of the defoliation and crop destruction missions on the HERBS tape.

Fig. IV B-7. Maps of north half of XT quadrangle showing forest vegetation and distribution of impacts

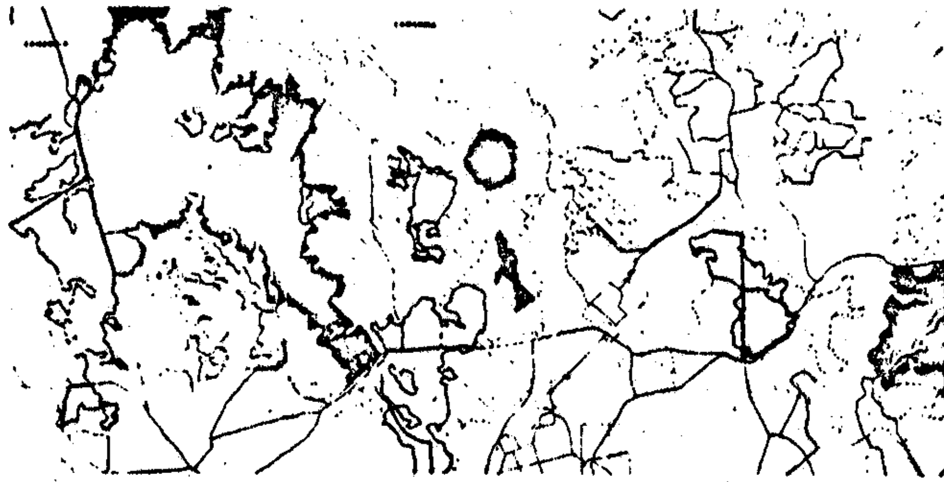
(a) Forest cover map:

Lowland Forest Type 1	100-70% forest 0-30% brush	
Lowland Forest Type 2	70-40% forest 30-60% brush	
Lowland Forest Type 3	40-10% forest	
Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings	
Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings	

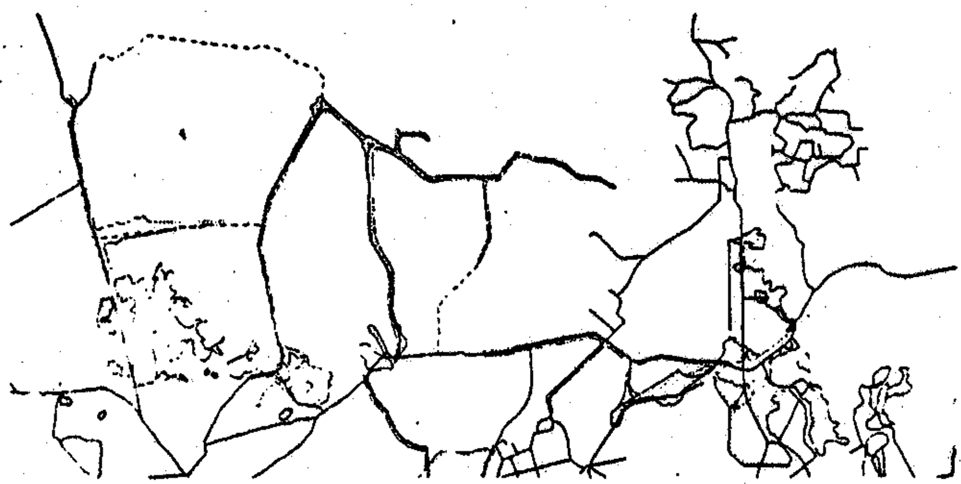
(b) Land clearing along roads and extensive areas (to the west) of urban and agricultural development and (to the east) military and agricultural clearing.

(c) Pattern of heavy bombing. Lines indicate length and density of sticks of B-52 bomb craters as seen in 1969 and 1971 aerial photographs.

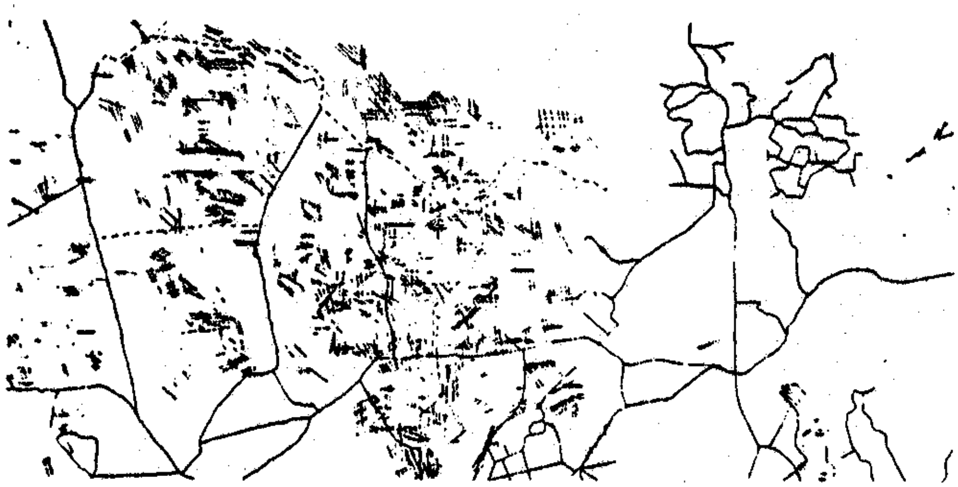
(d) Herbicide defoliant spray coverage for years 1965-71 is shaded. Black areas were sprayed four times or more.



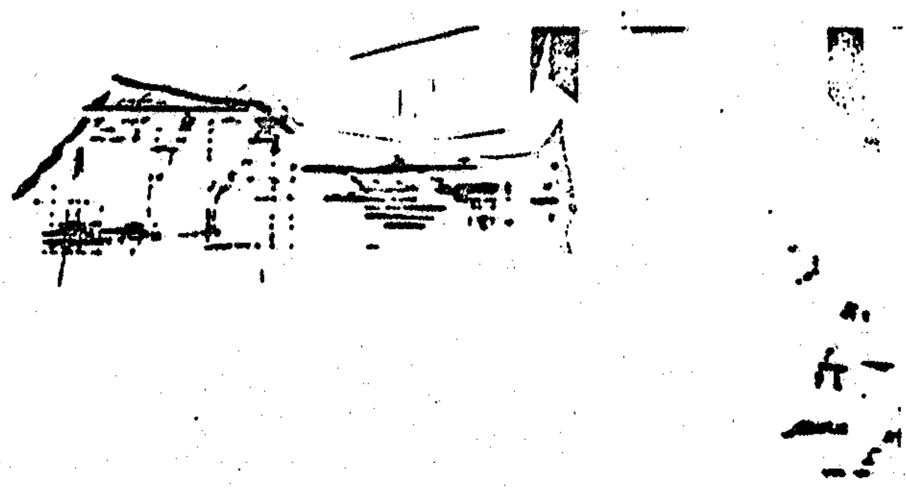
a



b



c



d

Fig. IV B-8. Maps of north half of YT quadrangle showing forest vegetation and distribution of impacts

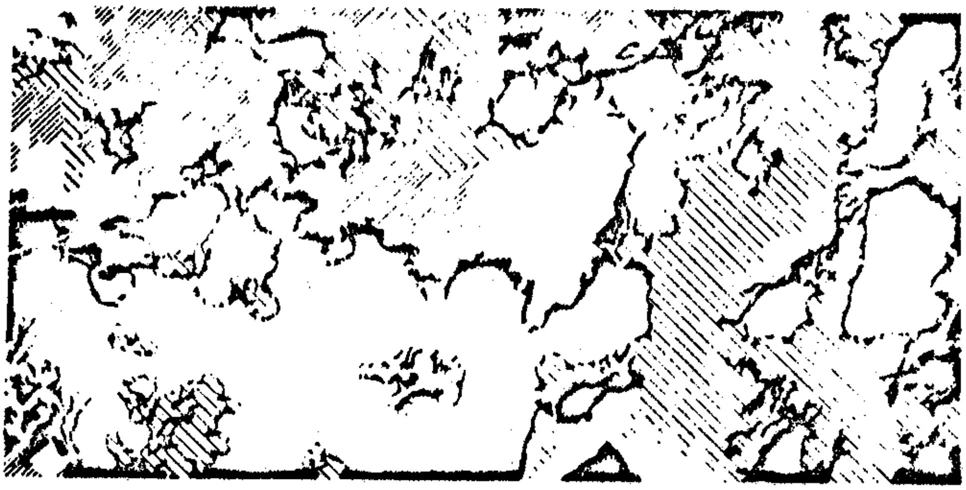
(a) Forest cover map:

Lowland Forest Type 1	100-70% forest 0-30% brush	Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings
Lowland Forest Type 2	70-40% forest 30-60% brush	Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings
Lowland Forest Type 3	40-10% forest		

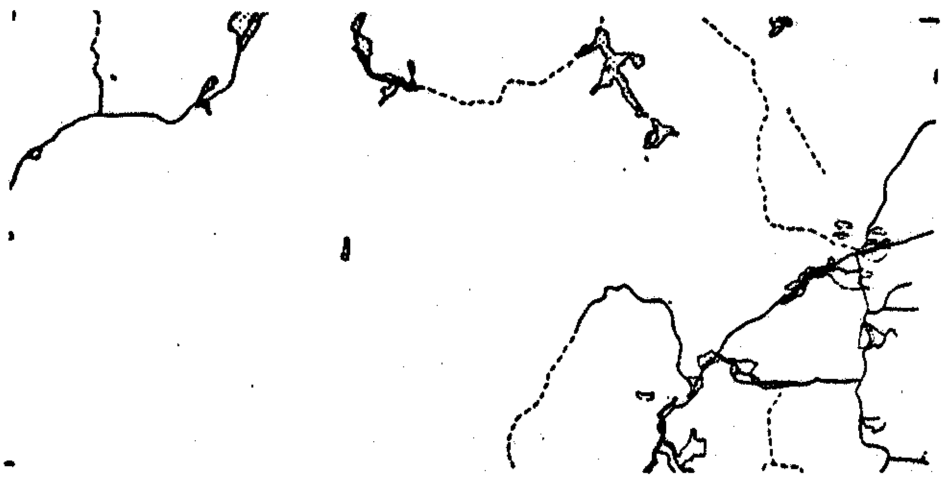
(b) Cleared land along roads and extensively cleared urban and agricultural areas.

(c) Pattern of heavy bombing. Lines indicate length and density of sticks of B-52 bomb craters as seen in 1969 and 1971 aerial photographs.

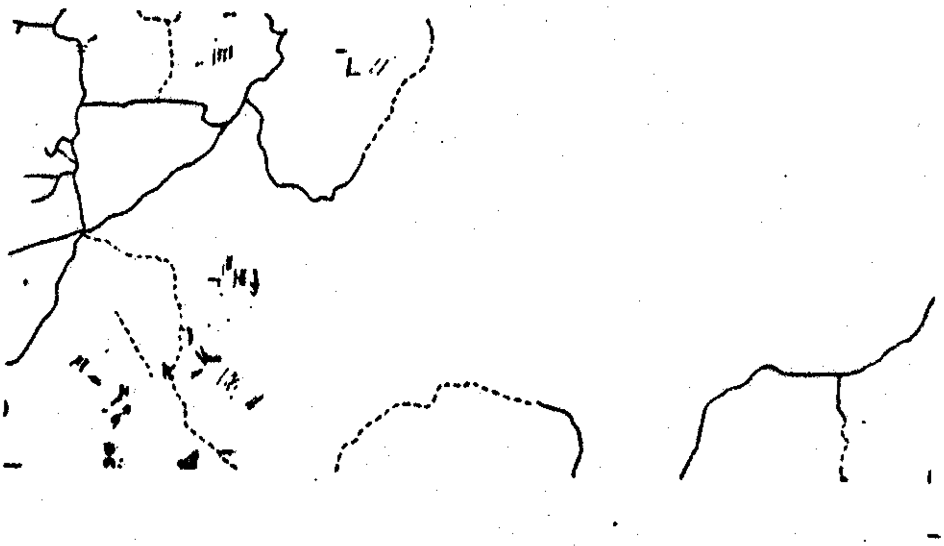
(d) Herbicide defoliant spray coverage for years 1965-1971 is shaded. Black areas were sprayed four times or more.



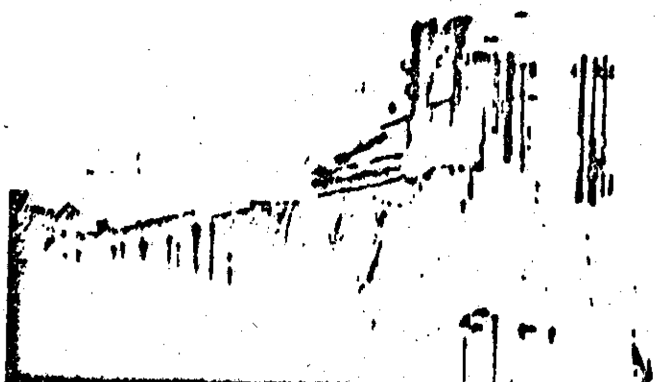
a



b



c



d

Fig. IV B-9. Maps of south half of YT quadrangle showing forests vegetation and distribution of impacts.

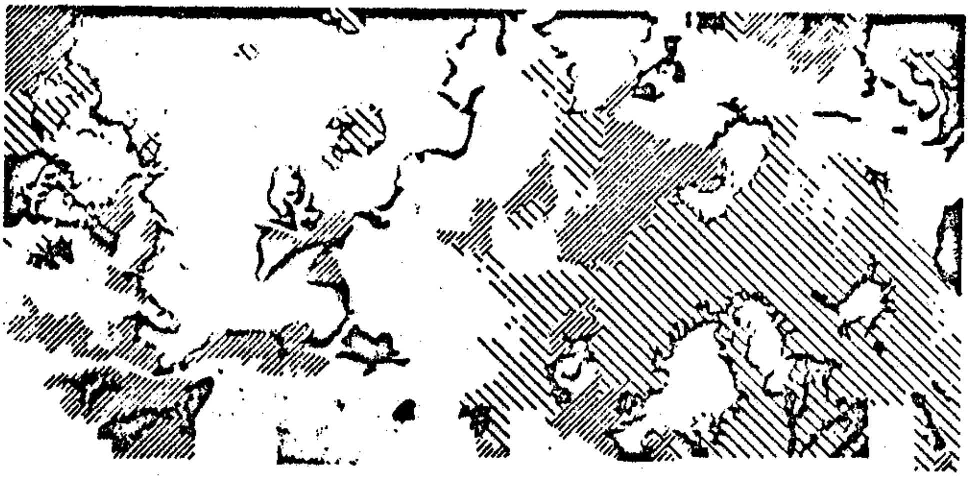
(a) Forest cover map:

	Lowland Forest Type 1	100-70% forest 0-30% brush
	Lowland Forest Type 2	70-40% forest 30-60% brush
	Lowland Forest Type 3	40-10% forest
	Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings
	Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings

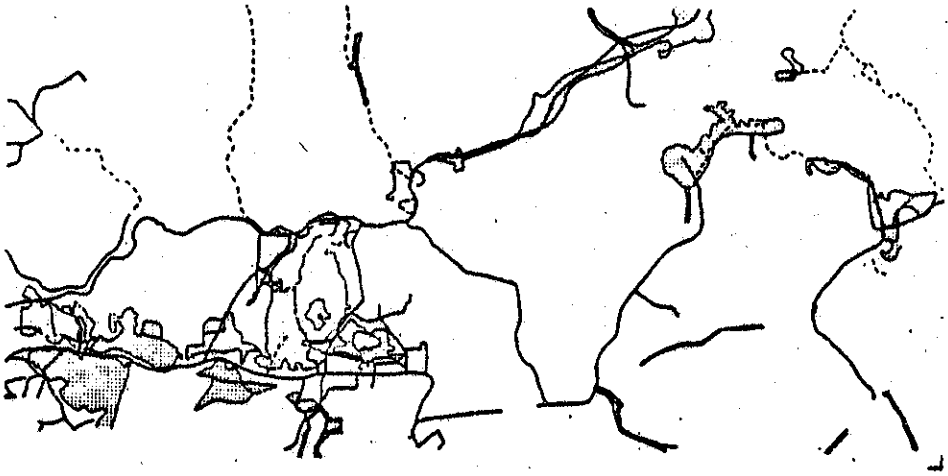
(b) Cleared land along roads and extensively cleared urban and agricultural areas.

(c) Pattern of heavy bombing. Lines indicate length and density of sticks of B-52 bomb craters as seen in 1969 and 1971 aerial photographs.

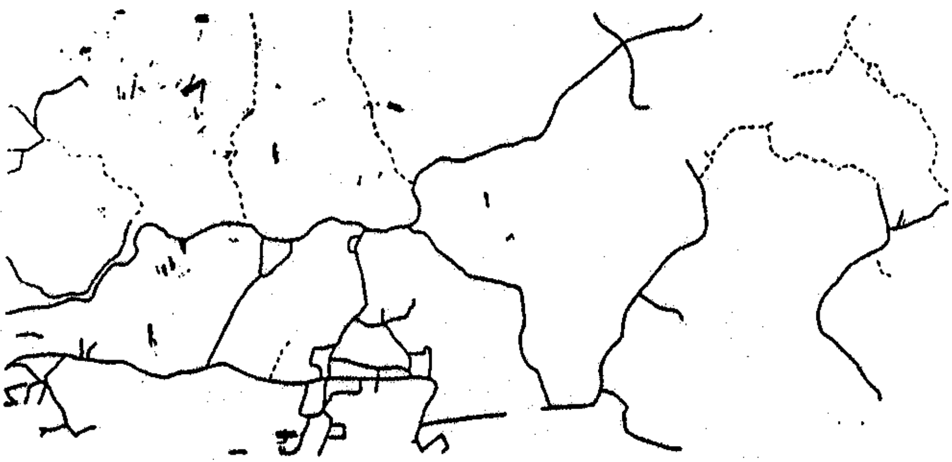
(d) Herbicide defoliant spray coverage for years 1965-71 is shaded. Black areas were sprayed four times or more.



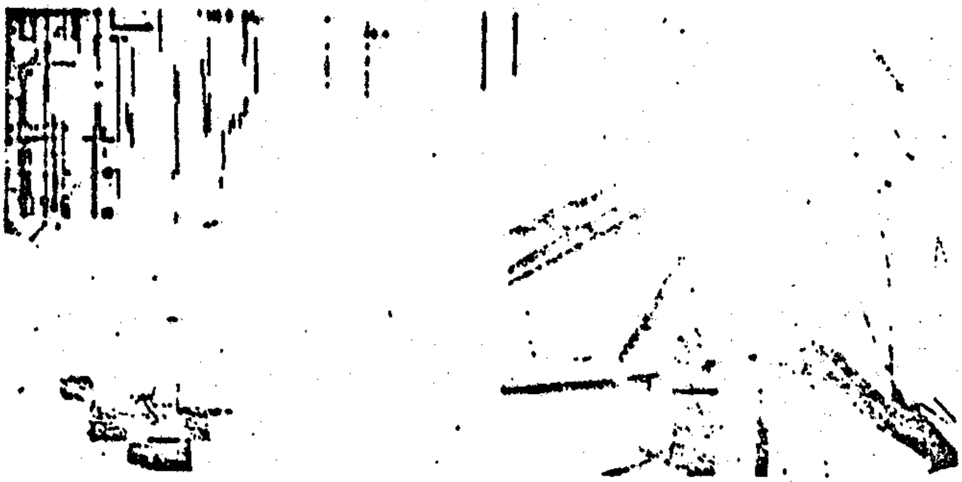
a



b



c



d

Assuming satisfactory figures can be obtained for the amount of kill of trees in the forest, there remains the question of evaluation. Clearly trees are not all of equal economic value. In terms of market value, the essential characteristics are the species of a tree and its size and quality. Some relatively rare species such as ebony (*Diospyros* spp.) and rosewood (*Dalbergia* spp. and *Pterocarpus* spp.) are of high value. These are in the Luxury class. Other species are of lesser but definite value (Classes I and II), while still other numerous species are of low value or no value for manufacturing and sometimes even for fuelwood.

In general, shrubby trees and bushes have little or no commercial wood producing value; seedlings, saplings, and pole size trees of valuable species have potential to grow into trees of sufficient size, but have no lumber or plywood value until they attain that size.

The market value of mature trees of valuable tropical hardwood species depends, on the one hand, on their size and quality, and on the other, upon relative scarcity and demand at a given time. The latter value will change as utilization opportunities change. New utilization opportunities may arise out of the development of a new manufacturing facility requiring new raw material, or out of increased opportunities to serve more remote markets. In SVN the opportunities for utilization of wood in manufacture of primary products are essentially confined to lumber and, to a much more limited extent, plywood.

In the remainder of this chapter, the available information on the inland forests is analyzed to answer as far as possible the following major questions:

a. What was the extent and character of forests in SVN before herbicide spraying started?

b. What kinds of impact, both military and non-military, have been applied to these inland forests, and what effects have resulted from these impacts?

c. What information and methods could be used to establish the amount of herbicide effect on the forests?

d. What standards should be used in assessing the extent of the herbicide damage?

e. What was the extent of the damage to merchantable timber by the herbicide?

f. What was the extent of damage to non-merchantable woody vegetation by the herbicide?

g. What is the estimated economic value of the loss?

h. What steps could be taken to rehabilitate the affected forest areas?

The following definitions were used in establishing the parameters for the study of merchantable timber loss:

Forest - Forest is defined as those major areas of land which fall into the following Rollet vegetation types, dense forests, secondary forests, semi-dense and open forests (Section III A). Pine forests were, however, excluded (Section IV A).

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, Hau-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 merchantable volume 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.

Standing Timber - Standing timber is defined as including timber on the stump, either standing in its original living form or as a dead tree, and trees which have been knocked down or uprooted but which are still essentially in place geographically.

Merchantable Timber - Merchantable timber[a] is defined as timber in log form 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.

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.

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 (see p. IV-45).

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

---

[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.

Observed Mortality Area - Observed mortality area is defined as the portion of the sample that was observed to have dead trees of merchantable or non-merchantable size or other dead woody vegetation.

Extent and Character of Forest in SVN Prior to Herbicide Spraying

As reference base for estimates of damage it is necessary to have an evaluation of the extent and character of SVN forests before the initiation of the herbicide operations. This involves an assessment of the mixture of forest types that make up the forest area of interest and the quantity of merchantable timber and non-merchantable wood in each of the forest types. A good forest inventory as of the date of the commencement of spraying would have provided such information. Since no such forest inventory had been made, it was necessary for the Committee to prepare such an inventory using the best data available.

The best information available in the literature on the pre-spraying forest types of SVN was the vegetation map of SVN prepared by Rollet in 1956 and the type descriptions and forest type development information contained in Rollet's vegetation analysis (Rollet, 1962a). Rollet's vegetation map of SVN, at a scale of 1:1,000,000, or approximately 16 miles to the inch, provided a major foundation for the study of damage over the country as a whole. Excellent 1958 aerial photographs, at a scale of 1:50,000, were available for the detailed study of MR III (Section III). It is important to understand how far the information from these photographs, a scale greater than one mile to one inch, differs from the information on the Rollet map.

The Rollet map was based upon 1:40,000 panchromatic coverage flown for the French National Geographic Institute in 1952-1953. Obviously one difference between the distribution of forest types as observed by Rollet, and observations made on the 1958 photographic coverage was the change in land-use status between 1953 and 1958.

Aside from influence by man, the type of vegetation in different parts of a country is a function of climate, soil, and topography. Over the long, narrow extent of SVN, ranging from latitude 8°33' to 17°00' north, the topography and soil vary from the extensive alluvial lowlands of the Mekong Delta to the rolling hills of the Terrace Region, then farther north to the high mountain ranges cleft by steepsided valleys. Approximately 10.5 million ha (26 million acres) of the country were classified by Rollet as covered in forest vegetation. Some of the types of vegetation (Table II E-2) are in broad botanical classes, but the major classes of forest, "dense" and "secondary" reflect influence of man. Authorities on the subject (Rollet, 1962a;

Williams, 1965) have stated independently that the forests of SVN have been heavily influenced by man for centuries. According to a translation of Rollet (1962a), little of the lowland forest is undisturbed; he says: "I believe that for the most part, the dense forests of the lowlands of South Indochina are old, secondary forests..."

Wood-cutting for fuel and timber logging have thinned out large areas of formerly dense forests, removing the larger trees and causing gaps in the canopy. An even greater impact has been from the practice of clearing and burning the forest to grow food crops (swidden agriculture). Sometimes the swiddens are abandoned after a few years, sometimes the cultivators return to them after the clearing has lain fallow for a number of years, but in either case the result is to replace large tracts of forest by a mosaic of clearings, brush, and secondary forest. Such areas, classified by Rollet (1962a) as "secondary forest, bamboo and shifting-cultivation zone, "generally contain few or no trees of merchantable size and quality and in aerial photographs at this scale appear very different from forest which has been undisturbed for a long time. The non-merchantable component of these forests may be very large. They constitute a potentially important part of the nation's forest growing stocks; potentially important because they serve this role only if they are not again cleared for farming before the older trees reach merchantable size. Thus, at the time of defoliation the forest varied from old growth, either little modified or with a more or less broken canopy (due to selective felling), to areas where few large trees are scattered over stands of smaller trees, brush, bamboos, etc.

It will be evident that the magnitude and kind of effects of herbicides (and any other war-related disturbances) as well as the value of any loss, will depend considerably on whether a sprayed area was covered in forest trees, bamboo, or shrubs and brush, and whether the trees were large or small, young or old, and of merchantable species. It is in no sense a criticism of Rollet's work to say that his admittedly broad classification of forest types is too broad to furnish sufficient detail for an assessment of damage. Since it was not feasible to study the entire herbicide-sprayed area of SVN in detail through aerial photographs, we undertook to establish, by means of an analysis of the 1958 black and white aerial photography 1:50,000 scale (Section III A), a classification of MR III using "macro-types" related specifically to use, occurrence, size, and distribution of trees. The major vegetation types so established are illustrated in Figs. IV B-10 through IV B-14. They are:

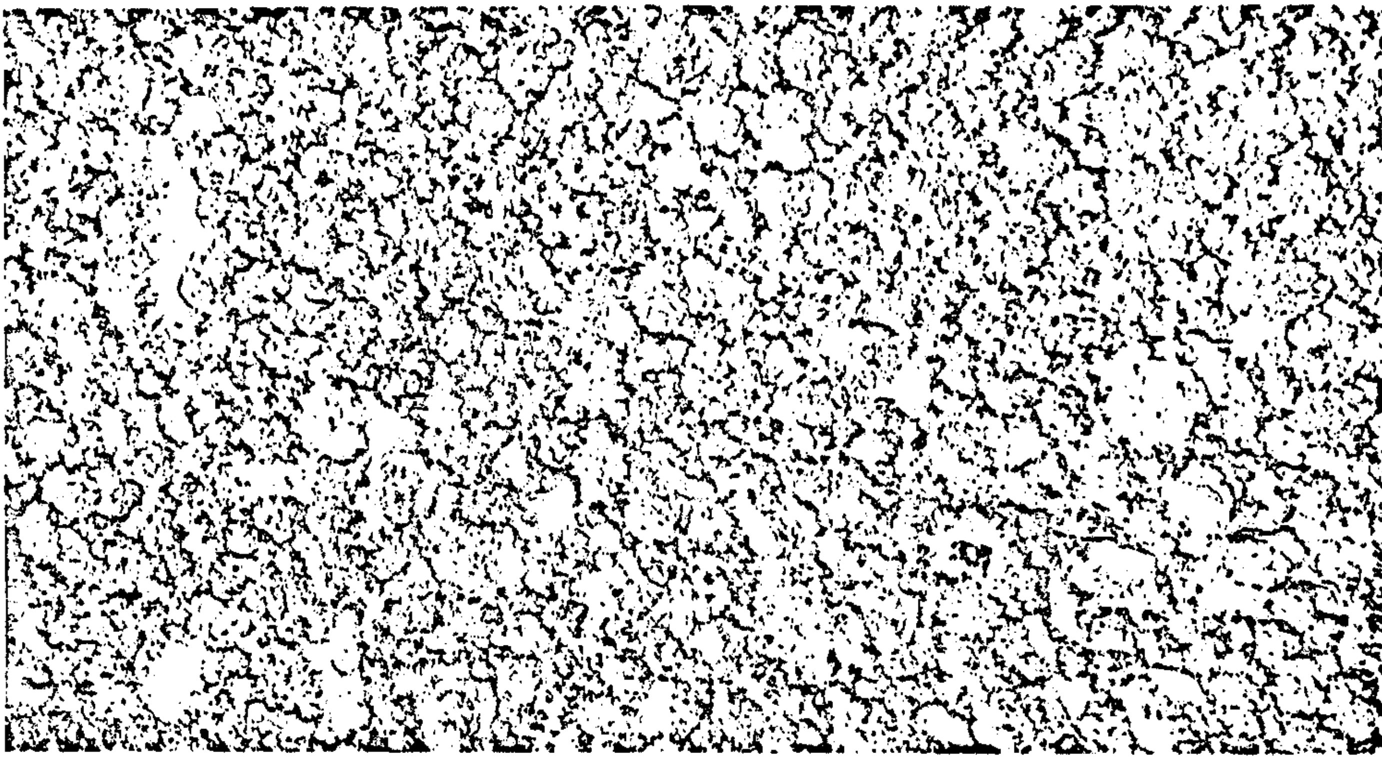


Fig. IV B-10. Lowland Forest Type 1. The Closed forest is comprised of trees (large, small, or in mixtures) with patches of bamboos and brush over less than 30% of the area. Photo taken in 1972 at a scale of 1:2,000.

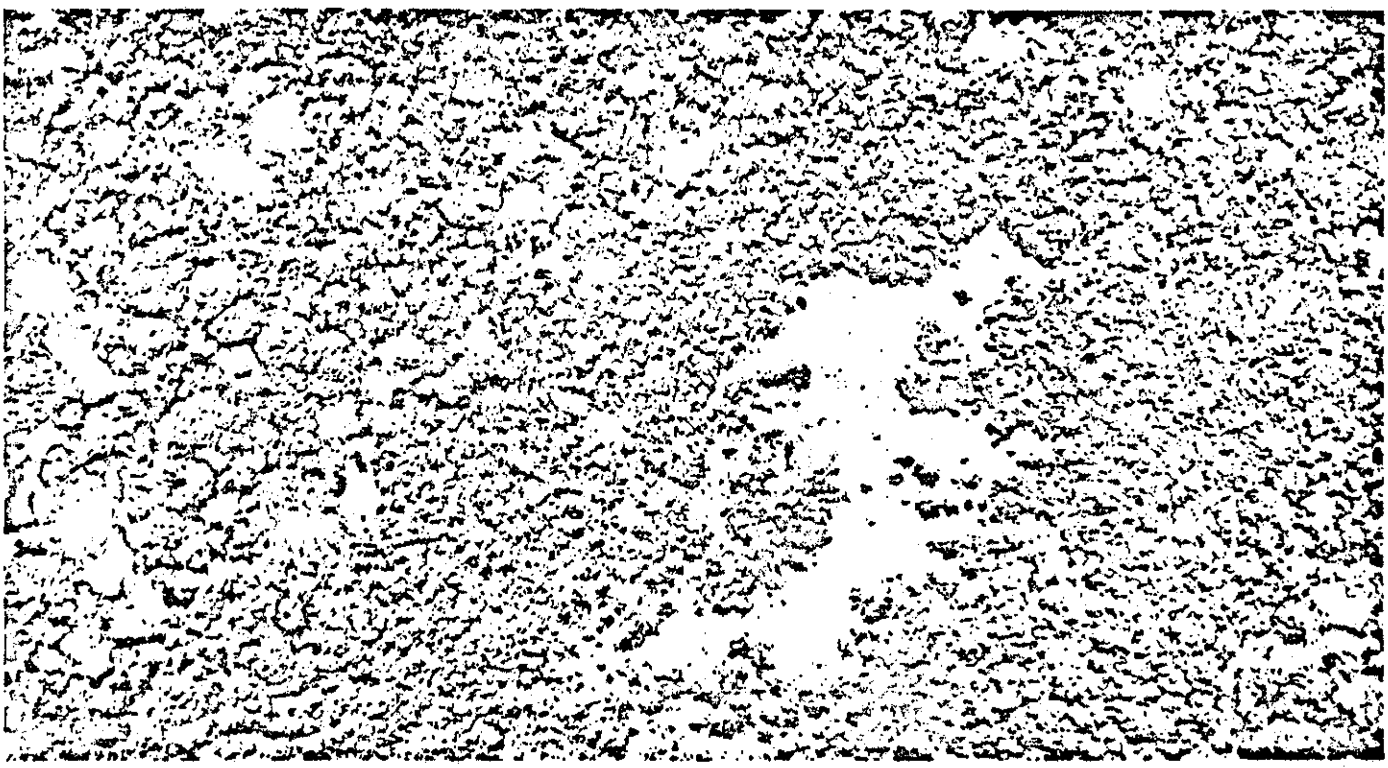


Fig. IV B-11. Lowland Forest Type 2. Similar type of forest to Type 1 but with bamboo, brush, and thickets comprising 30-60% of the area. Photo taken in 1972 at a scale of 1:2,000.

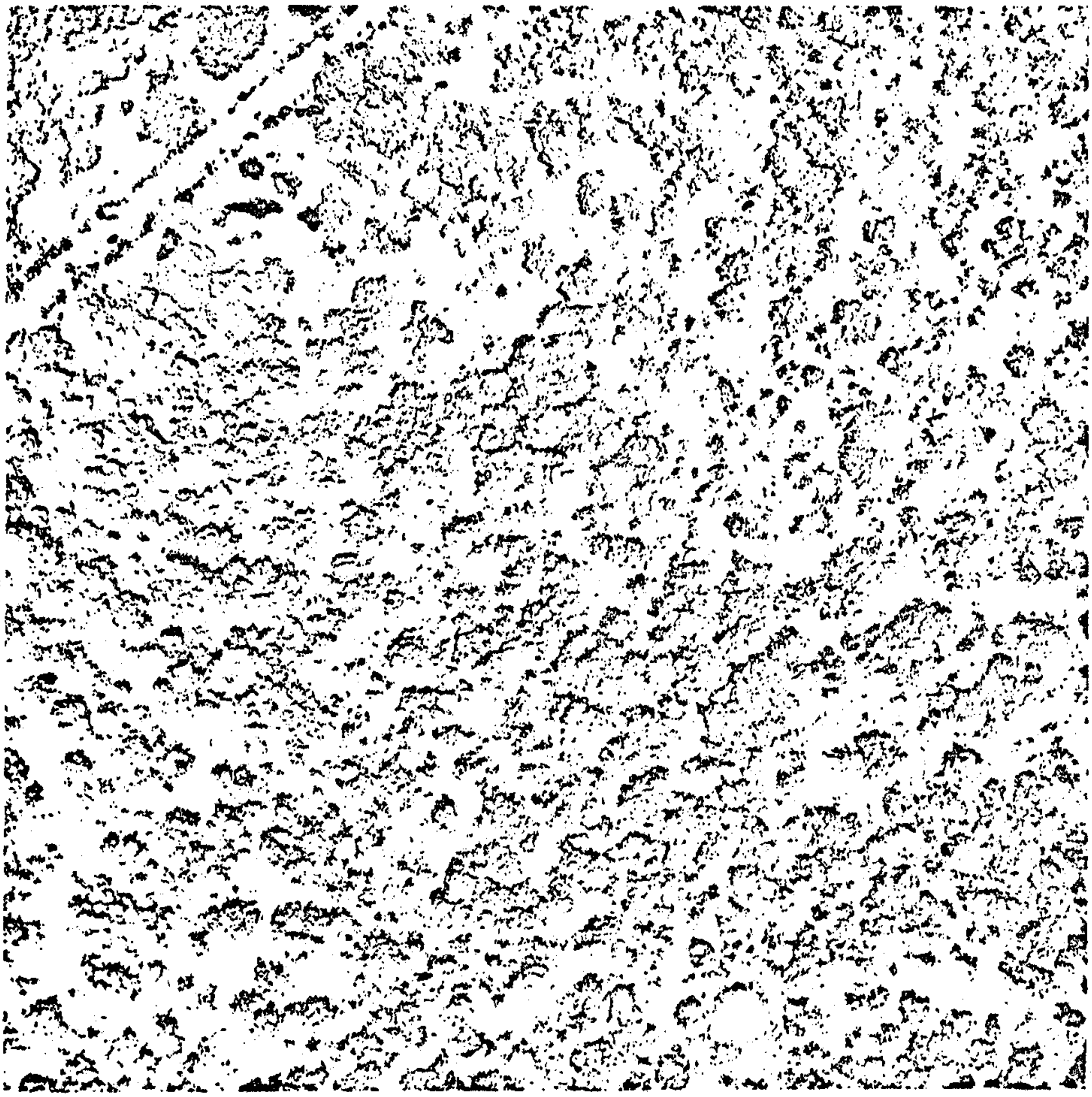


Fig. IV B-12. Lowland Forest Type 3. Mosaic of forest patches with extensive brush, clearings, and thickets of regrowth comprising 60-70% of the area. Photo taken in 1972 at a scale of 1:2,000.

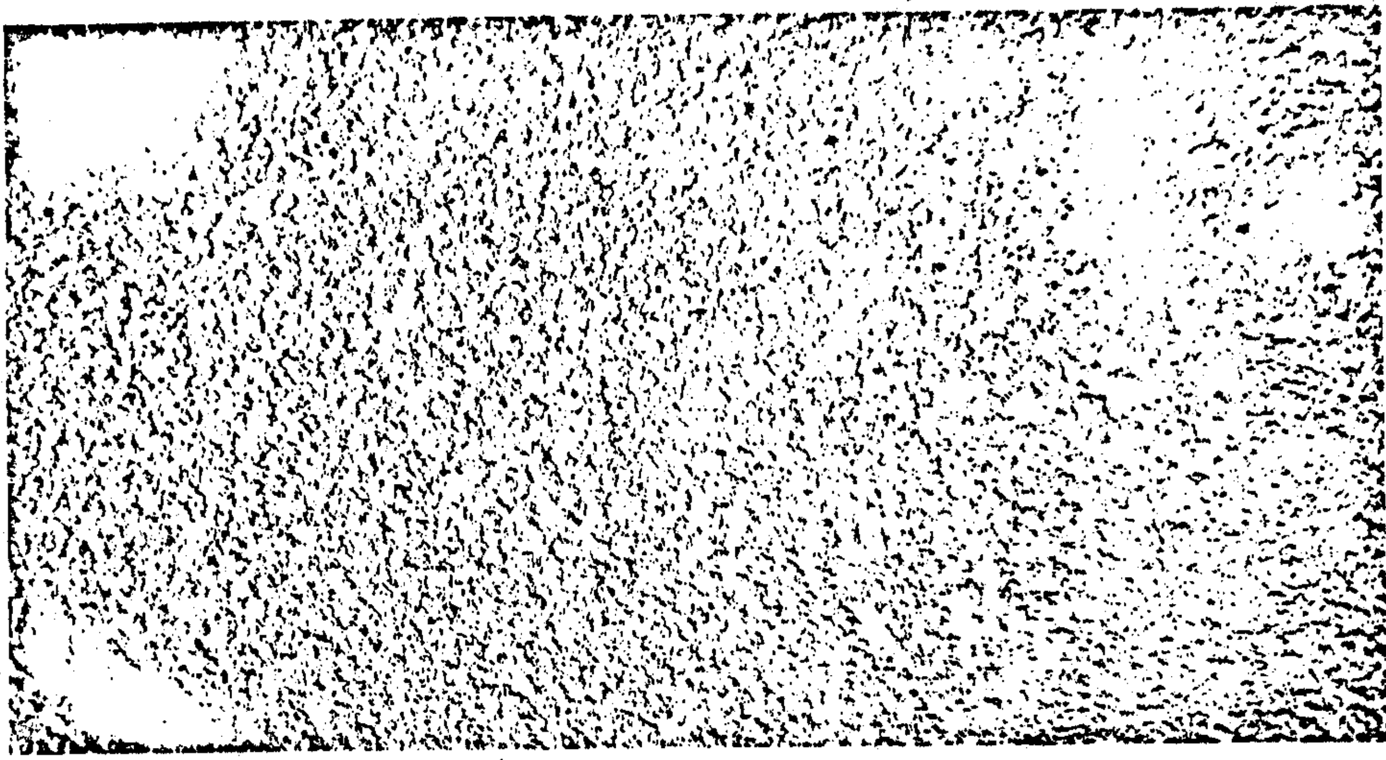


Fig. IV B-13. Cultivation Zone Type 1. Residual single trees and small clumps thinly scattered over largely inactive cultivation clearings, now covered with brush, bamboo, grasses, or small trees. Photo taken in 1972 at a scale of 1:2,000.

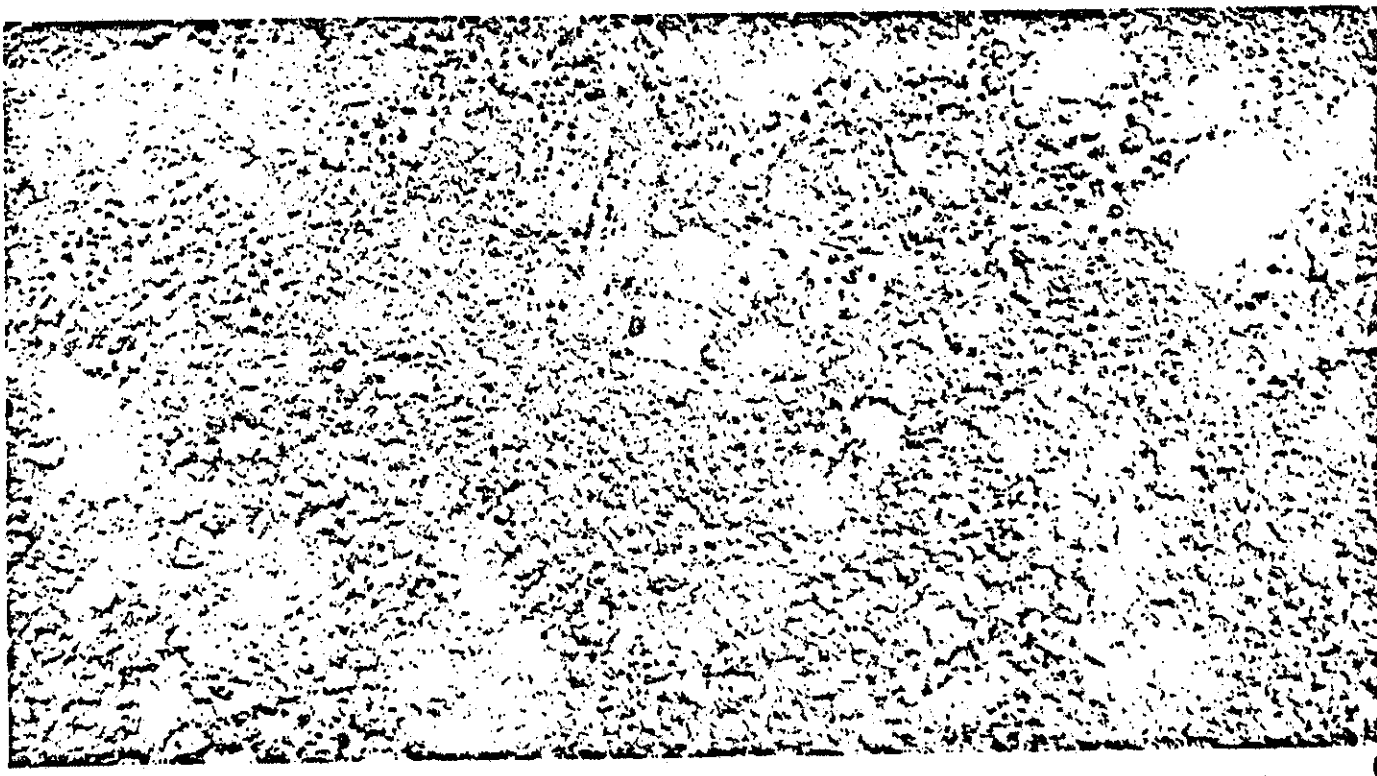


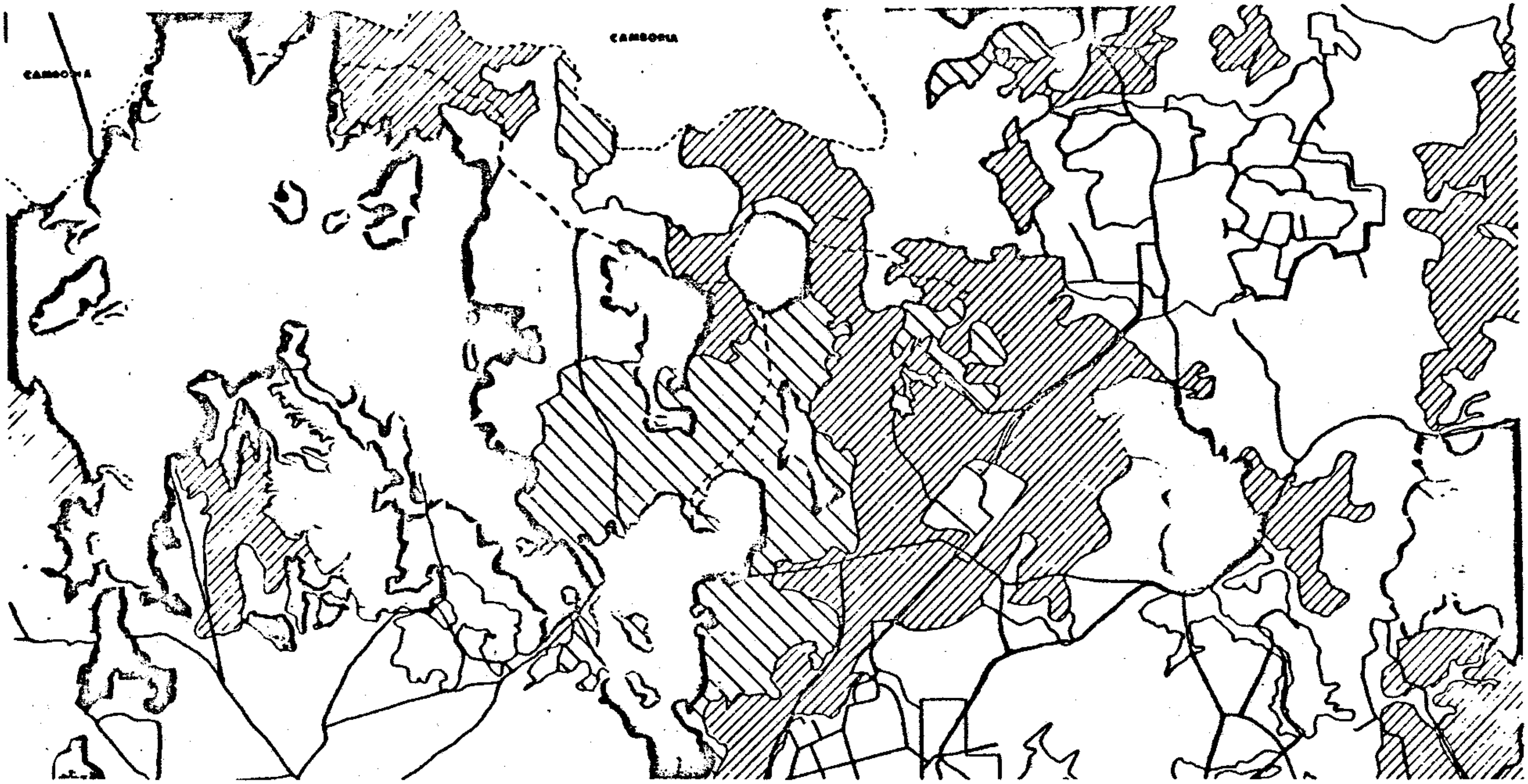
Fig. IV B-14. Cultivation Zone Type 2. Primarily swidden agriculture in mosaic of cultivated and fallow clearings. Very few scattered trees visible. Photo taken in 1972 at a scale of 1:2,000.

Lowland Forest Type 1: forest 100-70% brush 0-30%	Closed forest, are fully covered, trees may be large or small or mixture, with patches of bamboos and brush over less than 30 percent of area.
Lowland Forest Type 2: forest 70-40% brush 30-60%	Areas of closed forest as in 1, but with areas of bamboo, brush, and thickets comprising 30-60 percent of area.
Lowland Forest Type 3: forest 40-10% brush 60-90%	Mosaic of forest patches with extensive brush, clearings, and thickets of regrowth, comprising 60-90 percent of area.
Cultivation Zone Type 1:	Residual single trees and small clumps thinly scattered over largely inactive cultivation clearings, now covered in brush, bamboo, grass, or small trees.
Cultivation Zone Type 2:	Primarily active swidden agriculture in mosaic of cultivated and fallow clearings. Very few scattered forest trees visible.

This macro-typing provided the basis for estimating the pre-spray inventory of SVN. It was related to the Rollet vegetation typing to permit both an assessment of changes in land use between 1953 and 1958, and an extrapolation of inventory from MR III to all of SVN. Table IV B-1 shows the percentage composition equivalents of the Rollet vegetation types in terms of the macro-types based on the 1:50,000 scale 1958 photographs, and the percentage composition equivalents of these macro-types (1:50,000) in terms of the Rollet vegetation types. Figs. IV B-15 through B-17 show the Committee's macro-typing for the upper half of the XT Quadrangle, and the upper and lower halves of the YT Quadrangle, respectively.

Macro-typing of the sort that Rollet did and that of the Committee using the 1958 photos is broad in character. Areas given a particular classification will commonly include small patches of land that depart from the general type description. The Committee, therefore, went one step further and micro-typed a sample of the inland forest area in MR III.

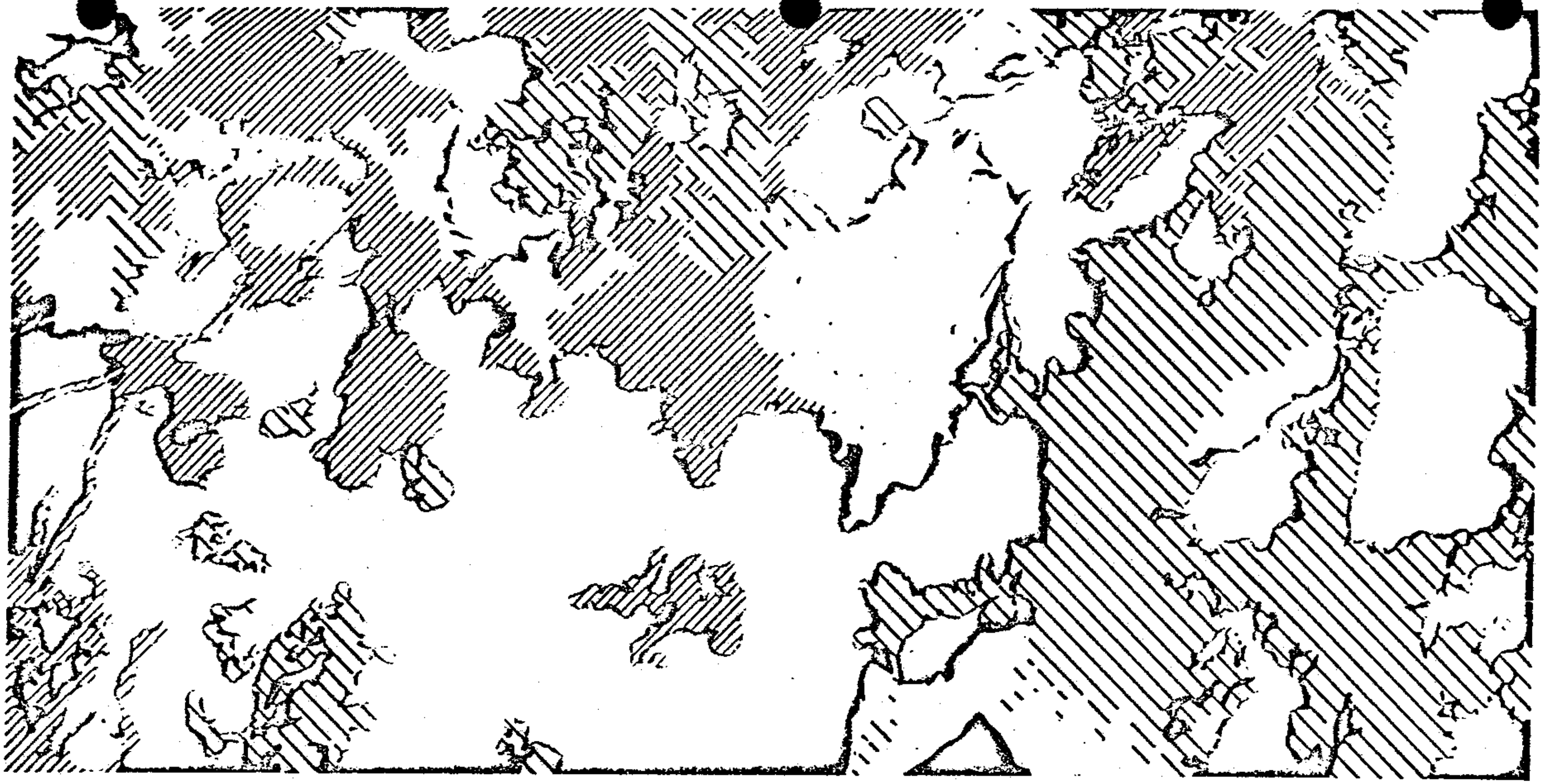
This micro-typing was carried out using the 1:5,000 scale aerial color photographs which had been taken in 1972-1973 (Section III A [2]) and which represents a sample equal to 9 percent of the MR III inland forest area. These photos were also used to evaluate numbers of live trees by size categories and for estimating an inventory and for determining tree mortality. The micro-types recognized on the 1:5,000 scale photographs are as follows:



Map of North Half of XT Quadrangle (100 km x 50 km)

Lowland Forest Type 1	100-70% forest 0-30% brush	Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings
Lowland Forest Type 2	70-40% forest 30-60% brush	Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings
Lowland Forest Type 3	40-10% forest		

Fig. IV B-15. Forest cover and residual forest and brush in shifting and swidden agriculture areas are indicated by shading. Unshaded areas are urban, permanent agriculture, rubber plantations, and wetlands.



Map of North Half of YT Quadrangle (100 km x 50 km)

	Lowland Forest Type 1	100-70% forest 0-30% brush		Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings
	Lowland Forest Type 2	70-40% forest 30-60% brush		Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings
	Lowland Forest Type 3	40-10% forest			

Fig. IV B-16. Forest cover and residual forest and brush in shifting and swidden agriculture areas as indicated by shading. Unshaded areas are urban, permanent agriculture, rubber plantations, and wetlands.

Map of South Half of YT Quadrangle (100 km x 50 km)

Lowland Forest Type 1	100-70% forest 0-30% brush	
Lowland Forest Type 2	70-40% forest 30-60% brush	
Lowland Forest Type 3	40-10% forest	
Cultivated Zone Type 1	Scattered trees and inactive swidden agricultural clearings	
Cultivated Zone Type 2	Scattered trees and active swidden agricultural clearings	

Fig. IV B-17. Forest cover and residual forest and brush in shifting and swidden agriculture areas as indicated by shading. Unshaded areas are urban, permanent agriculture, rubber plantations, and wetlands.

Code	Size[a]	Description
1 (secondary)	Small trees	Bamboo with a few trees
2 (secondary)	Small & medium trees	Trees and bamboo (about 1/2 on the basis of crown area)
2_1 (secondary)	Small & medium trees	Brush and bamboo
3 (secondary)	All sized trees	Trees (ground not generally visible)
3_1 (secondary)	All sized trees	Trees and brush
4 (open or thin)	Small & medium trees	Trees (ground visible)
4_1 (open or thin)	Small & medium trees	Trees and bamboo
4_2 (open or thin)	Small & medium trees	Trees and brush
5 (closed)	Large trees	Trees (ground not generally visible)
6 (non-forest)	Not applicable	Shifting agriculture or area otherwise disturbed
7 (non-forest)	Not applicable	Rivers, crops, settlements, roads, etc.
8 (non-forest)	Not applicable	Grass

Tables IV B-1 and IV B-2 show the percentage composition of Committee macro-types in terms of these micro-types, and the percentage of micro-types in terms of the macro-types.

---

[a] The merchantable size classes are:

Small trees	=	10-20 m crown diameter
Medium trees	=	20-30 m crown diameter
Large trees	=	30 + m crown diameter

All forest types include, in addition to the merchantable size class trees, growing stock in less than merchantable size classes, and other non-merchantable trees and shrubs.

Table IV B-1.

Comparison of Inland Forest Composition in Military Region III According to the Vegetation Types of Rollet and the Committee's Macro-Types

(The Rollet types (Section III A-1) were transferred (by means of outlines on transparent overlays) from the Rollet (1956) map (1:1,000,000) onto the aerial photographs, World Wide Survey 1958 (1:50,000) on which the vegetation had been classified according to the Committee macro-types.)

A. Percentage composition of the five Committee macro-types in terms of the Rollet types.

Committee Macro-Types		Rollet Vegetation Types						
		1	2	3	4	5	15	Total
Lowland Forest Type	1	50	17	6	0	21	6	100
	2	17	28	3	0	49	3	100
	3	4	48	3	4	38	3	100
Cultivation Zone Type	1	4	24	8	1	54	9	100
	2	4	17	0	1	75	3	100

B. Percentage composition of the Rollet inland forest types in terms of the Committee macro-types.

Committee Macro-Types		Rollet Vegetation Types					
		1	2	3	4	5	15
Lowland Forest Type	1	75	16	33	0	13	28
	2	10	10	6	0	11	5
	3	5	40	14	67	20	12
Cultivation Zone Type	1	7	26	47	20	36	49
	2	3	8	0	13	20	6
Total		100	100	100	100	100	100

Table IV B-2

Comparison of Inland Forest Composition in Military Region III According to the Macro- and Micro-Types Established by the Committee.

Procedure was the same as in Table IV B-1, but the macro-types established by means of the 1958 1:50,000 photography were compared with the micro-types established with the 1972-1973 1:5,000 photography.

A. Percentage composition of the macro-types in terms of the micro-types.

Macro-Types		Micro-Types												
		1	2	2_1	3	3_1	4	4_1	4_2	5	6	7	8	Total
Forest Types	1	2	24	2	52	9	0	0	2	2	7	0	0	100
	2	3	28	0	9	4	0	0	0	0	22	2	32	100
	3	0	0	0	28	28	0	0	0	0	25	0	19	100
Cultivation Types	1	0	2	12	0	39	0	0	2	0	45	0	0	100
	2	23	0	12	3	34	0	7	11	0	8	1	1	100

B. Percentage composition of the micro-types in terms of the macro-types.

		Micro-Types											
		1	2	2_1	3	3_1	4	4_1	4_2	5	6	7	8
Forest Types	1	6	51	6	83	13	100	0	17	98	11	8	1
	2	9	46	0	12	4	0	0	0	0	26	53	96
	3	0	0	0	0	0	0	0	0	0	0	0	0
Cultivation Types	1	0	3	42	0	40	0	0	10	2	52	0	0
	2	85	0	52	5	43	0	100	73	0	11	39	3
Total		100	100	100	100	100	100	100	100	100	100	100	100

Inventory of Merchantable Volume

A forest inventory for SVN was estimated using the following information:

a. An area of inland forest of 10,390,000 ha from Rollet (1956).

b. An estimate of the percentage of the forest in each micro-type using the Rollet vegetation typing and the macro-type analysis.

c. An estimate of the average number of trees of merchantable size from analysis of the 1:5,000 scale photographs.

d. An estimate of the fraction of merchantable size trees that are of merchantable species based on comparable data from an inventory of Cambodia east of the Mekong River (Rollet, 1962b).

e. An estimate of the utilizable volume of the merchantable trees based upon a study conducted in the forest products mills of SVN by the Committee.

These inputs to the estimated merchantable forest inventory are discussed in detail in the following paragraphs.

The area of inland forests used in the determination of an estimated forest inventory for SVN is 10,390,000 ha. This includes the closed dense and secondary forests and the Dipterocarp and *Lagerstroemia* forests as indicated in the simplified Rollet classification shown in Table II E-2 of this report, but excludes the pine forests which occupy only a small area (180,000 ha) and which have had relatively little herbicide exposure. The inventory estimate does not include tree volumes on areas included under other Rollet classification types.

Using the distribution of micro-types as determined from studies of the sample represented by the 1:5,000 scale color photography, the fraction of the total inland forest area in MR III that was in each micro-type was estimated. In estimating the forest inventory for all of SVN it was assumed that these type-area relationships apply to the areas of SVN outside of MR III that were in the Rollet types included in the total inland forest area. Examination of aerial photography for areas outside of MR III suggests that this assumption is not greatly in error but the Committee did not have low-level, high-resolution photography for the forested areas of MR I and MR II; thus to the extent that this assumption may not be valid the estimate of forest area by type may be in error.

The number of live trees of merchantable size for each micro-type was determined by analyzing the 1:5,000 scale color photographs. Merchantability standards in terms of size were determined by studying the logs being used for the manufacture of lumber and plywood in SVN during the Winter of 1972. For the latter purpose, a study was made of the average size of logs of utilizable species in the landings, log yards, and mill yards in SVN during the Winter of 1972. Included in the study were 43 sawmills and one plywood factory. This sample represented about 10 percent of the nation's active sawmills and its only plywood plant. On the basis of these data a 45 cm minimum diameter breast height (dbh) was assumed to be appropriate.[a] A small fraction of the trees currently being used in SVN factories are in fact smaller than 45 cm; however, a comparison of this distribution of tree diameters with stand diameter distributions representing comparable forest types as reported in Cambodian and Thailand forest inventories indicates that most trees are harvested to minimum diameters substantially above 45 cm dbh (Gartner and Beuschel, 1963). Because of this the actual merchantable inventory volume based upon current utilization standards in SVN represents probably some overestimate. For any given time the appropriate minimum harvesting standards could be determined by comparing utilization practice with stand composition by species and the inventory adjusted accordingly. Such a comparison in SVN can, however, only be made when security conditions permit field checks of forest stands.

The determination of the number of merchantable trees in photographic samples was made by stereoscopic examination of the samples. The estimation of tree diameter was based upon a relationship between crown diameter and tree diameter for Southeast Asian hardwood trees. The use of crown measurements as a basis for estimating dbh for inventory purposes is a recognized forest mensuration technique. No field measures of tree diameter and crown diameter were available for the inland forests of SVN and to obtain them was impossible. It was decided, therefore, to utilize existing information from other countries whose forest types are similar to those of SVN. Crown maps and stand data were obtained from three locations in Thailand.[b] These crown diameter-dbh data were obtained from forests in Thailand representing a wide variety of species growing under various ecological conditions. These forests and locations were:

---

[a] The dbh was calculated from log measurements assuming an average stump height of one m (3.3 ft) and a breast height of 1.5 m (4.9 ft).

[b] The crown maps and stand data from Thailand were prepared by a cooperating group of forest scientists from Kasetsart University, Bangkok, working under the direction of Sanga Sabhasri, at that time Dean of the College of Forestry and Vice Rector of the University.

a. Dry evergreen forest, Sakaerat Experiment Station
b. Dry dipterocarp forest, Sakaerat Experiment Station
c. Moist evergreen forest, Kao Yai National Park

The data for the tallied trees from these forests consisted of the dbh plus the average of four crown diameter measures taken from the crown maps. A further set of measurements was obtained from data published by Macabeo (1957) in a study relating stump diameter and crown diameter of luan (*Pentacme contorta*) trees in the Philippines. In order to use these data an adjustment from stump diameter (assumed at 1.0 m) to dbh (at 1.5 m) was made.[a]

The data were fitted to an equation of the following form by the method of least squares.

$$\log_{10} y = 0.76 + 0.89 \log_{10} x$$

where:

y = tree diameter breast high in centimeters

x = crown diameter in meters

coefficient of determination (r^2) = 0.92

variance = 0.17

For the purpose of developing stand tables for merchantable volume inventory estimation, trees were classified into three size classes as follows:

Merchantable tree size class	Crown diameter range (m)	Stem diameter range (cm)
Small	10 to 20	45 to 85
Medium	20 to 30	85 to 120
Large	30 and greater	120 and greater

[a] Since the tree tally was to be made from aerial photographs there was some concern that smaller merchantable trees might be obscured by tree crowns in the upper canopy. A study of the stand maps for the Sakaerat plots indicated that all trees in these multi-storied all-aged stands with dbh above 45 cm, as indicated by crown measurements, were visible from above. Out of 13 such trees on a one-quarter ha plot six had 100 percent of their crowns exposed, an additional three had more than 90 percent of their crowns exposed, and eleven out of the thirteen had more than 80 percent of their crowns exposed. The other two had more than one-third of their crowns exposed. Using stereoscopic examination it was possible to determine tree diameter from crown measurements for all of these trees. It should be noted that these forests had greater stand densities than the vast majority of the SVN forests surveyed.

The net utilizable merchantable volume per tree for each size class was based upon the utilization study made in the mills, log yards, and landings in SVN. Tree length logs and tree log multiples were measured and evaluated. Volumes calculated are for actual delivered logs. Individual log volumes were computed using the Hoppus log rule. Log volumes determined through the use of log rules differ from those derived from tree volumes computed for general forest inventory purposes essentially in that the former provide for a reduction in volume to account for those portions of the log that are lost in the conversion process and become mill residues.

In interpreting these inventory estimates it should be clearly understood that market value is based on the log scale and not on standing volume. The solid volume of wood standing in the forest is only a starting figure. The basis for sale is an estimate of actual volume of square sawn lumber that can be produced from the round logs. Log rules are used to make this estimate. The Hoppus rule, which was used to determine merchantable volumes in the utilization study, is commonly used in SVN and neighboring countries. In this study a total of 1154 logs from sixteen of the most commonly used species were evaluated. For each log taper, dbh and Hoppus volume were estimated. The following equations denote the method by which each was determined.

Calculation of dbh:

$$\text{Taper} = \frac{\text{large end diameter (cm) - small end diameter (cm)}}{\text{log length (m)}}$$

$$\text{dbh (cm)} = \text{large end diameter (cm)} - (0.5)(\text{Taper})$$

Calculation of volumes:

$$\text{Volume (Hoppus ft}^3) = \frac{1}{144}\left(\frac{C}{4}\right)^2 L \qquad \text{English system}^{a}$$

where

C = circumference at mid-length in inches

L = length in feet

The logs were assumed to be cut a stump height of 1.0 m (3.3 ft) and the dbh was taken to be at a height of 1.5 m (4.9 ft). Table IV B-3 summarizes the data on log scale by quality class from the utilization study. In SVN as in other areas of Southeast Asia, woods are marketed according to classes that reflect their value and utility. The classes used in this study and the species allocation to class are according to McKinley (1954) as follows.

---

[a] The actual calculations were done using the metric equivalents.

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

Class I: Woods characterized by great resistance to insects 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 I 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.

Table IV B-3 summarizes the results of the utilization study. The distribution of merchantable trees in the inland forests of SVN could not be determined in the field. For the purpose of inventory estimate it was assumed that the quality class distributon was similar to that in the forests of Cambodia east of the Mekong. The classification used by Rollet in the Cambodian inventory categorizes several important species one class higher than the classification reported by McKinley and used in the SVN market. For example, Lagerstroemia, one of the most common species in SVN, is listed as a Class I wood in Cambodia and as a Class II wood in SVN. Pahudia cochinchinensis is listed as a Luxury wood in Cambodia and a Class I wood in SVN. A number of other woods are listed in one higher class in Cambodia than in SVN. Accordingly, the use of Cambodian classifications for distribution purposes may result in a somewhat inflated merchantable inventory figure. Based upon the Cambodian inventory, it was assumed for the purposes of developing a SVN inventory that 69 percent of the small trees, 77 percent of the medium sized trees, and 66 percent of the large trees were of merchantable species.

Table IV B-4 gives the data from the photographic samples which formed the basis for the calculation of a pre-spray inventory of MR III. On the basis of these computations the estimated merchantable volume for the region was 16 million cubic meters. Table IV B-4 gives the inventory values for each micro-type. MR III includes 20 percent of the merchantable forest of SVN. Assuming that the forest structural composition for MR I and MR II is similar to that of MR III, an estimate of the merchantable forest inventory of the whole of SVN would be 82 million m^3. It should be noted that this merchantable volume inventory figure does not include the mangrove forests and the Melaleuca woodlands nor does it include the pine forests. These excluded forest types represent approximately four percent of the forest area of SVN.

Table IV B-3

Log Volume Data From Utilization Study

Class	No. of Logs	Percent of Total Logs	Average dbh (cm)	Average Vol. (m^3)	Percent of Total Volume
Luxury	154	13.3	48.7	0.77	5.9
I	253	21.9	71.6	2.06	25.8
II	707	61.3	65.2	1.83	64.0
III	40	3.5	79.1	2.21	4.3
Total	1154	100.0	(64.9)	(1.75)	100.0

Table IV B-4

Basic Data from Photographic Samples for Inventory Computations

Micro-Type	% of area in type	No. of merch. size trees per ha	No. of merch. size trees of merch. species per ha	Estimated merch. vol. m^3 Hoppus	Estimated vol. per ha m^3 Hoppus	Mean tree vol. in samples ha m^3 Hoppus
Closed Forest without substantial brush						
2	24.4	7.02	4.92	23,643,700	9.33	1.90
3	22.4	10.80	7.63	35,496,400	15,25	2.00
5	2.6	14.20	10.21	7,464,860	27.63	2.71
Open Forest						
4	0.7	6.80	4.72	600,311	8.25	1.75
Bamboo Forest and Forest with substantial brush						
1	5.2	1.20	0.83	782,685	1.45	1.75
2_1	10.2	3.89	2.70	4,958,020	4.68	1.73
3_1	10.3	4.05	2.81	5,259,380	4.91	1.75
4_1	0.8	3.47	2.42	365,426	4.40	1.82
4_2	2.3	2.99	2.10	959,984	4.02	1.91
Non-Forest						
6	10.9	1.58	1.09	2,063,010	1.82	1.67
7	6.9	0.07	.05	55,835	0.08	1.60
8	3.3	0.20	.14	77,590	0.23	1.64
Summary of Type Classes						
Closed Forest	49.4	9.11	6.43	66,604,960	12.98	1.99
Open Forest	0.7	6.80	4.72	600,311	8.25	1.75
Bamboo & Brush	28.8	3.38	2.35	12,325,495	4.12	1.76
Non-Forest	21.1	.87	.60	2,196,435	1.00	1.64
TOTAL ALL TYPE CLASSES	100.0	5.70	4.01	81,727,201	7.87	1.85

In interpreting this merchantable volume inventory estimate it may be useful to note what others have said about the useful volume of timber in this and comparable forest areas. In discussing the abundant lowland forests of SVN Rollet (1962a) suggests an exploitable volume of 8 to 13 m^3/ha "under actual exploitation practices and conditions." In the description of the inventory of Cambodia east of the Mekong, Rollet (1962b) says "it must be considered that a dense forest is very rich when it yields 15 meters cubed per hectare of currently commercial timber." Data from the inventory of the forests of Northeast Thailand give average merchantable volumes of about 17 m^3/ha.

This merchantable volume inventory estimate is greatly different from the average per hectare estimate of the merchantable volume of the inland forest affected by spraying that was used by Flamm (1970) and Westing (1971). It is appropriate to ask how one estimate of merchantable volume can be as high as 100 m^3/ha and others for the same and similiar forest areas can be in the range of 8 to 15. The answer to this question involves three main considerations: (1) the average composition of forest types in the region in question, (2) the mix of forest types in the region, and (3) the basis for determining appropriate standards of merchantability.

Concerning the first consideration, in the case of the inland forests of SVN, there are undoubtedly areas in which the total tree stem volume is 100 m^3 or larger, but the merchantability standards currently used in SVN reduce the merchantable volume even of these high volume areas to a very much lower figure.

As regards the second of the above three considerations, the inland forest area of SVN including the approximately 1,000,000 ha that were sprayed with herbicide contained little of this quality of forest and a very large proportion of forest remnants scattered widely within a mosaic of swidden agriculture clearings and young regrowth and brush. Even the dense secondary forests contain gaps, bamboo patches, and marshy areas. Figs. IV B-10 through B-14, representing the macro-types used in this analysis, provide an indication of this mixture of different forest quality. Hence, even though the most dense areas do in places carry high volumes per hectare, these high figures have to be averaged with very low figures from many other areas in obtaining the grand means to apply to extensive tracts. This important fact is by no means unique to the SVN forests but it is basic to all large-scale forest inventories. It does not, however, strike the eye of an observer in a helicopter who may see areas of heavy timber but may not mentally average these with the less dense and the vacant patches encompassed within the area designated on a map as forest.

The third consideration is the appropriate standard of merchantability. For example, if fuelwood were included in the merchantable wood category the inventory would be very much larger as will be shown in the discussion of the non-merchantable timber inventory. Since most of the biomass of the trees in a forest is potentially useful as fuel such inclusion could in principle increase the inventory on some specific areas by a factor of perhaps five to ten. This could come about in a number of ways. For example, when trees are cut for sawlogs and veneer logs, the logging residue (the remainder of the woody stem and crown) could presumably be cut up and used for fuel. Trees not useful for lumber or plywood because they are of unacceptable species or unacceptable quality could presumably be harvested and cut up for fuel. In point of fact this level of utilization is rarely achieved even in those parts of the world where wood for all uses is in very short supply. It is never even remotely approached in the forests of SVN where the supply of wood for all but the most highly specialized current uses is abundant while the supply for fuel, in the forest, far exceeds requirements.

It should be noted, too, that the merchantable inventory for a specific forest area can be immediately increased if merchantability standards are changed to permit use of currently non-merchantable species, smaller trees, larger portions of the presently merchantable trees, and more defective specimens of presently merchantable species. Thus, the existence of pulp mills, fiberboard or particle board plants might change utilization standards dramatically. This is, of course, a situation that prevails in many tropical countries. A meaningful merchantable inventory, however, can be based only upon wood utilization facilities that are actually available.

Kinds of Impact and Effects

Like extensive forests in any part of the world, those in SVN are composed of many stands of different age, size, structure, and species composition. The kind and amount of damage caused by any disturbance depends on these stand characteristics as well as the kind and amount of the disturbance. As explained at the outset of this chapter, effects of forest disturbance can be considered in the categories of loss of merchantable volume, loss of growth, and loss of growing stock (plus loss of seed source), and our principal, quantitative effort was directed at determining the first category.

Merchantable volume is the amount of timber of such species and size as is saleable in the current market. Precise specifications and measurement standards are described later. This volume is in the bole[a] of the larger trees which due to their greater height often form a canopy over smaller trees. When dense native stands are cleared for agriculture or selectively harvested for timber, the remaining

---

[a] The bole is that portion of the tree stem that lies between the top of the stump and the first branch.

large trees are commonly scattered widely as single trees or clumps. The trees of commercially valuable species which have not yet attained merchantable size are referred to here as the growing stock. This recognizes the fact that the future crop of merchantable trees will in time emerge from that component of the forest. As these smaller trees grow, many die naturally due to crowding by neighbor trees; over the years the composition changes from many small trees to a few large trees.

As explained before, the major classes of war disturbances have been bombing and shelling, clearing, and herbicide application. Fig. IV B-18 shows a small example of heavy bomb strikes. The map in Fig. IV B-7 gives the distribution of heavy bombing visible in 1969 and 1971 photographs; in the northern part of Tay-Ninh Province areas bombed earlier are now barely detectable, hence the map gives only a partial picture of this impact. It is evident that extensive areas were heavily bombed. Large-scale photographs show craters of an average diameter of 10 m (33 ft).

The total effect of heavy bombing was to demolish all merchantable trees and growing stock immediately adjacent to the craters, and to break tops and flatten growing stock further back from the craters (Fig. IV B-19). Where sticks of bombs have exploded in close proximity, the forest is reduced to ragged strips of surviving trees between the rows of craters. Many of those surviving carry embedded bomb fragments. A single stick of large bombs effectively demolished woody vegetation in an area averaging 128 by 2140 m, i.e., 27 ha or 67 acres (Fig. IV B-20).

It was not within the mandate of the Committee to assess the bomb damage, hence no detailed study was made. But the approximate area of heavily bombed forest shown in the map (Fig. IV B-7c) is 65,000 ha which is 13 percent of the total area in that map. This refers only to bomb damage clearly evident in 1968 photographs; much of the earlier damage is now obscured by vegetation (Fig. IV B-21) and later bombing in that area was also heavy.

Land clearing occurred in a number of forms; associated primarily with military operations were roadside clearing to reduce ambush danger, establishment of military camps, storage areas, etc., and clearing of extensive areas for resettlement of civilian refugees. The term "clearing" here means that areas of forest, scrub, and brush were bulldozed clear of all vegetation, the mass of trees and branches being piled and completely burned after they had dried.

Extensive areas were cleared also to remove cover for enemy movements and operations in locations other than roadsides. For example, the areas at the lower right on Fig. IV B-7b were apparently cleared for this reason.

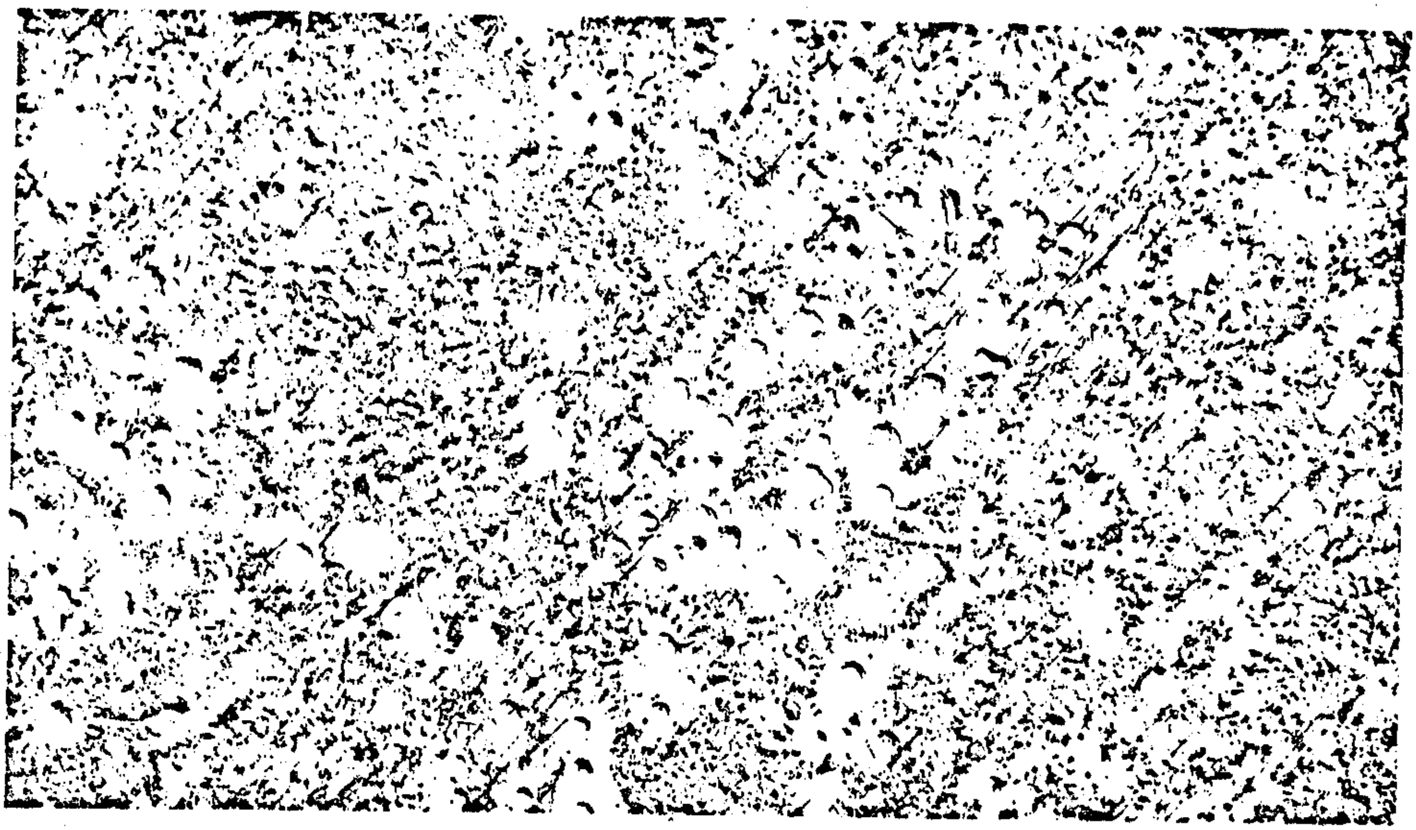


Fig. IV B-18. An example of heavy bomb strikes. Photo taken in 1972 at a scale of 1:2,000.

Fig. IV B-19. Recent bombing of secondary forest showing areas cleared of all forest vegetation. Photo taken in 1972 at a scale of 1:2,000.

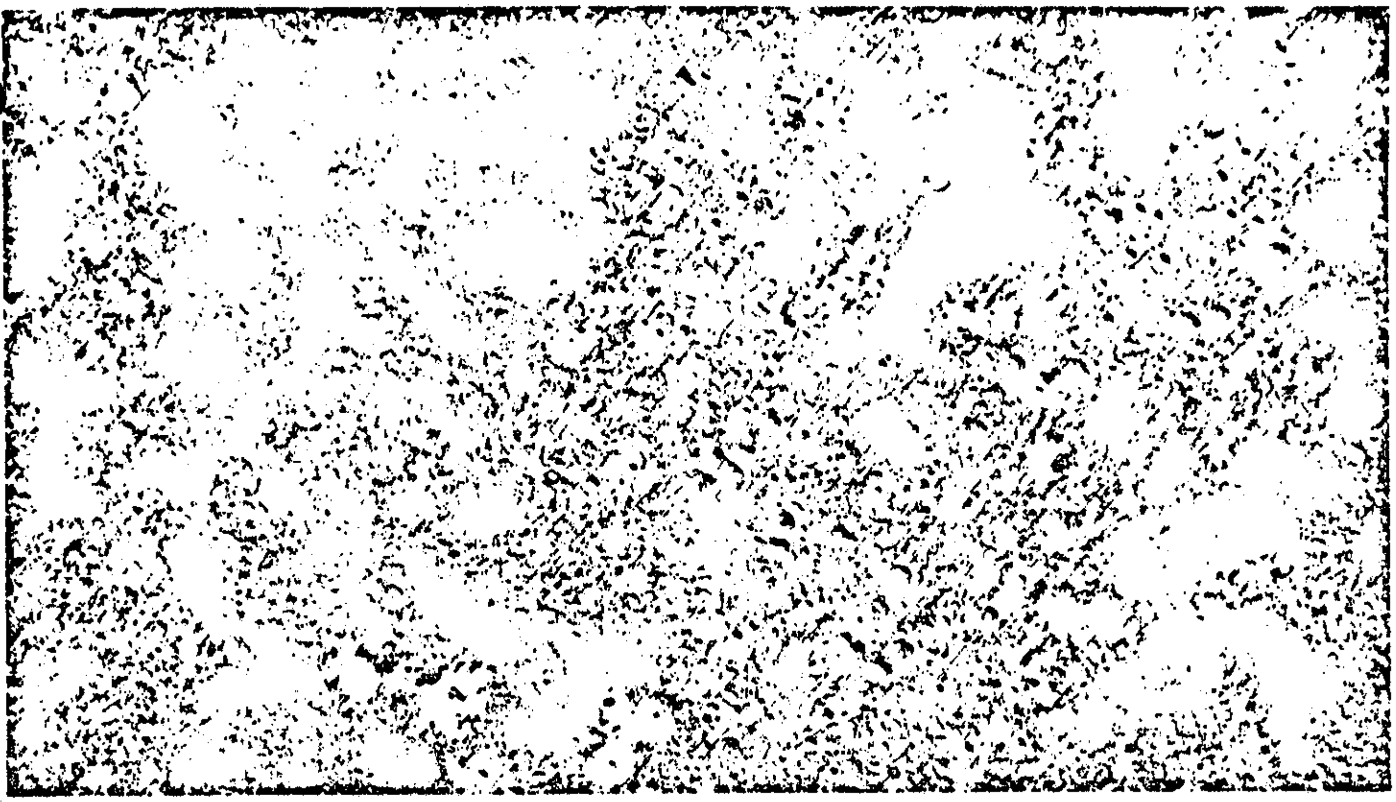


Fig. IV B-20. Bomb damage to forests showing strips cleared by sticks of bombs.

Fig. IV B-21. Older bomb damage showing lack of definition as forest recovers. Such damage appears as white streaks on large scale photographs.

The third form of military disturbance, herbicide application, caused defoliation and kill of susceptible species. Some trees were killed by one dose and the kill increased markedly with repeated application, the spacing in time of multiple applications being undoubtedly an important factor in this respect (Fig. IV B-22). Within the inland forest sprayed by defoliation and crop destruction missions the distribution of herbicide was as follows:

No. of herbicide exposures (impacts)	Hectares Sprayed	Percent
1	694,386	64.29
2	251,439	23.28
3	90,540	8.38
4	31,410	2.91
5 +	12,262	1.14
Total	1,080,037	100.00

Using 1:5,000 aerial photographs areas sprayed once, twice, three times and four or more times were compared for evidence of damage to merchantable size trees. It was clear from this analysis that areas sprayed once rarely suffered any significant damage. Damage was usually light on areas sprayed twice. Those areas sprayed three or more times showed heavy damage with the level of damage increasing markedly with increased spray frequency. Figs. IV B-24 through B-27 show areas sprayed once, twice, three and four times. Not only merchantable size trees were killed but also smaller ones; hence both merchantable volume and growing stock were killed. The loss in seedlings and small trees cannot be assessed from aerial photographs of the scale available. Other trees lost their foliage and often part of the crown was also lost but the tree survived: in these cases the loss would be the reduced growth during and, if part of the crown was killed, following the defoliated period. Yet other trees were unaffected. A major task of the Committee was to assess the kill in the various tree categories. An indication of the extent of spraying is given in Fig. IV B-7d where the shaded portions indicate all areas covered by defoliation missions; the blackened portions represent areas sprayed four times or more.

Civilian impact on the forest was in the form of urban development, agricultural clearing, and harvesting for fuelwood and timber. Several of the major towns expanded considerably between 1958 and 1969. Often the surrounding forest was cleared to provide agricultural land.

Conspicuous near towns and along roads is a progressive removal of stands of small trees, presumably for fuelwood and/or light construction. At first a few foot paths become visible but over the years a maze of trails develop and the stand of trees is reduced to scattered remnants and brush. Since spraying was widespread, fuel cutting often happened in areas already sprayed. Where new roads were constructed there is evidence of timber cutting; when this was near a town which also exhibits expansion, it is reasonable to suspect the cut trees contributed lumber for the construction of houses.

Fig. IV B-22. Area in north XT quadrangle sprayed from 4 to 7 times showing heavy large tree mortality from herbicide treatment.

Fig. IV B-23. Area in north XT quadrangle showing combination bomb damage and herbicide damage. Areas heavily treated with herbicide were commonly also heavily bombed.

Fig. IV B-24. Area sprayed once with herbicide. Note brush and small trees in inactive swidden clearings.

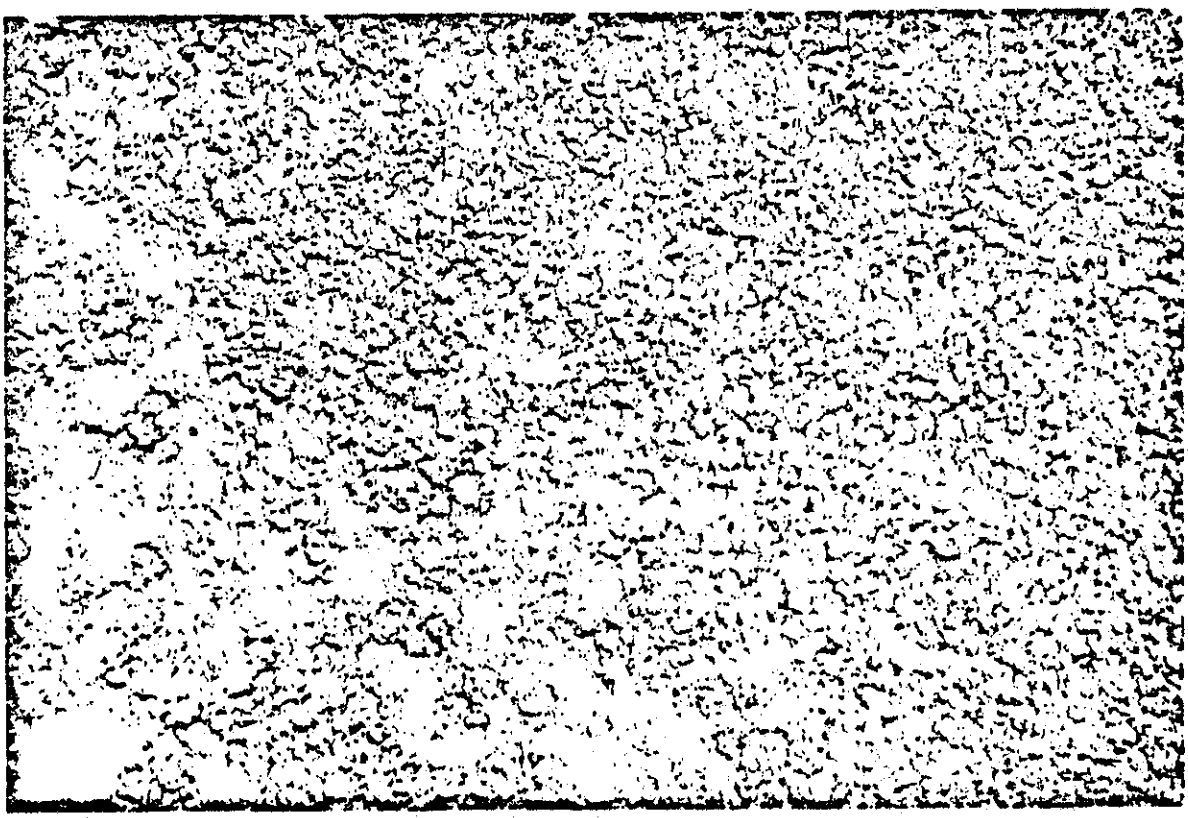


Fig. IV B-25. Area sprayed twice with herbicide.

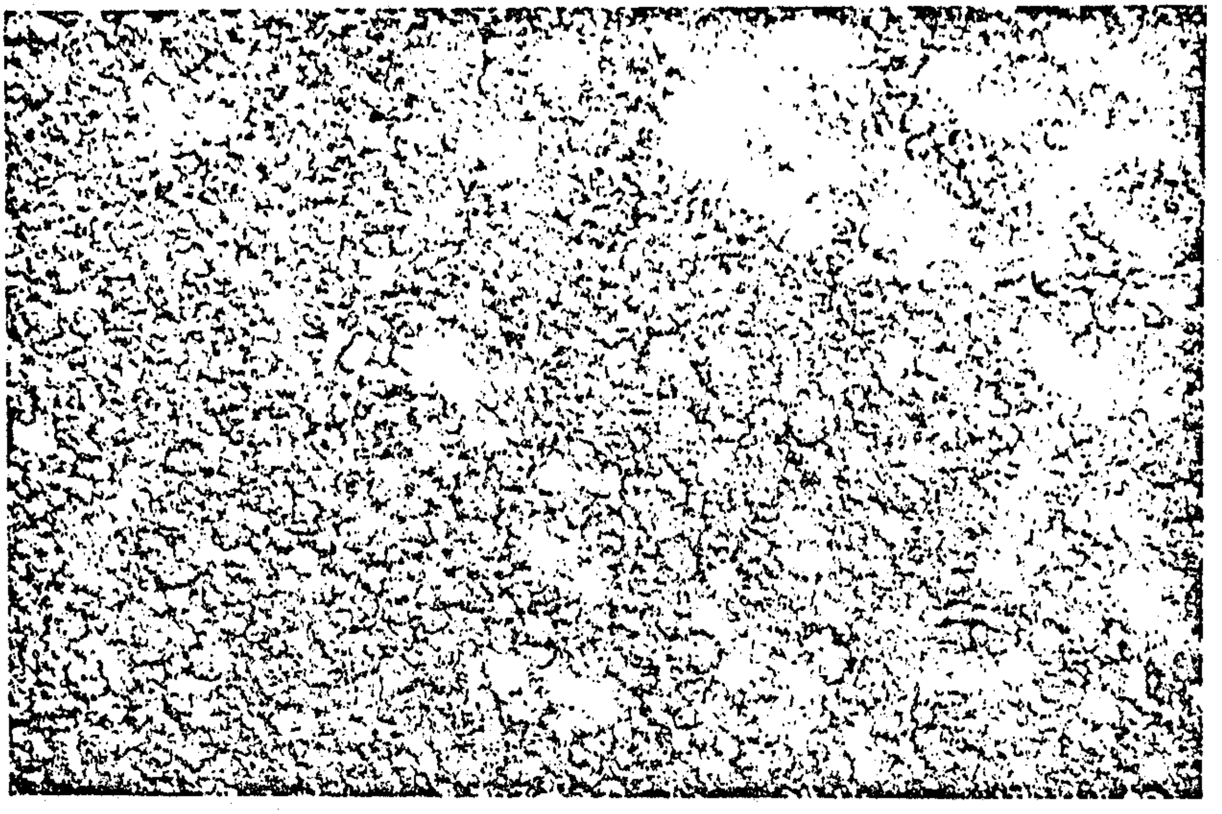


Fig. IV B-26. Area sprayed three times with herbicide.

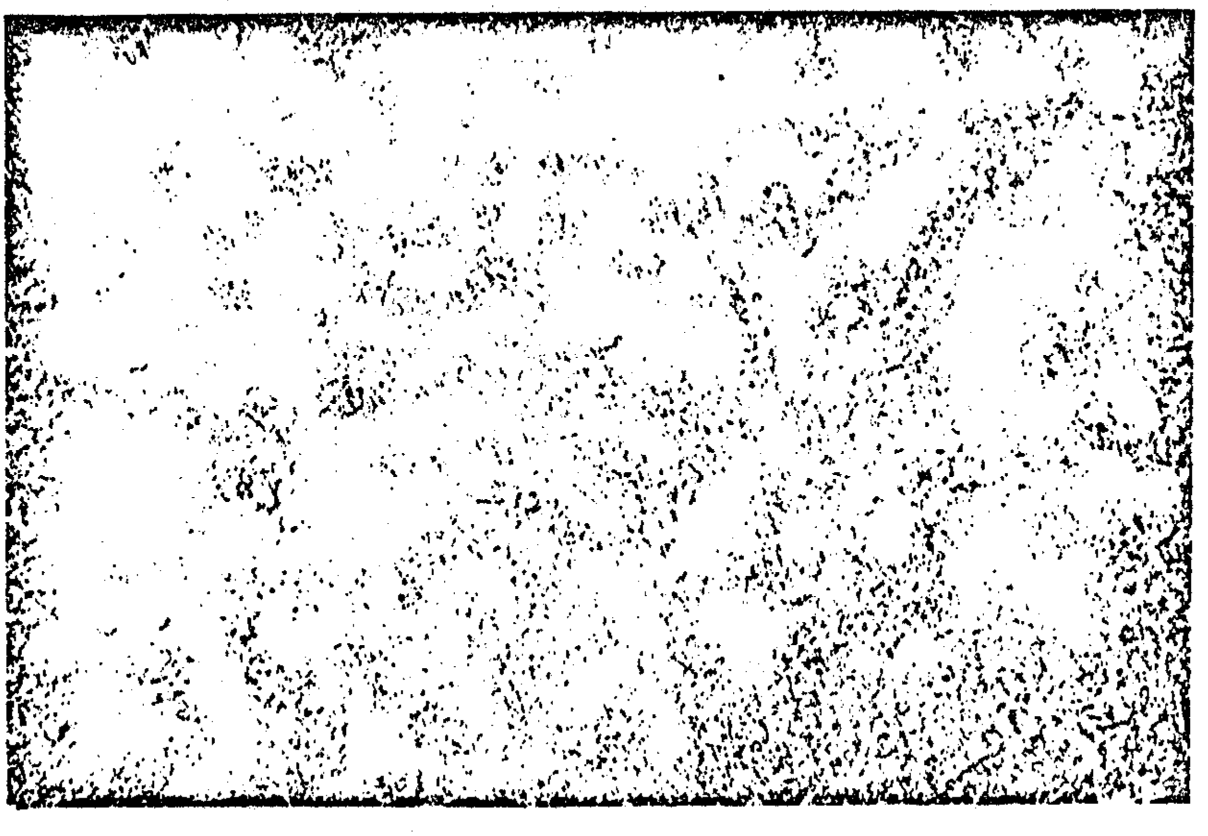


Fig. IV B-27. Area sprayed four times with herbicide.

It should be quite clear from the maps in Fig. IV B-7a through 7-d that the military and civilian impacts were often intermingled, and that heavy bombing occurred widely over the same areas where herbicide was sprayed (Fig. IV B-23).

Assessment of Merchantable Timber

The assessment of merchantable timber damage is based upon an estimate of dead trees in the forests of SVN.

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 Fig. IV B-28.

Every third low-level photograph was sampled in order to avoid photo-overlap. Each frame was subdivided into 162 (9 by 18) quadrats of equal size, each quadrat corresponding to 1.5625 ha (about 3.7 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 12 forest types considered (Table IV B-5). 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 ha.

A rectangular area in the center of each photographic frame was used as the sub-sample area in which dead trees were counted. This sub-sample area was of 12 quadrats by 5 quadrats and equivalent to 93.75 ha (about 235 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).

In each quadrat, dead merchantable trees were counted and recorded according to the forest type within the quadrat. Many quadrats had no dead trees of merchantable size. The number of quadrats in which dead merchantable size trees were observed converted into total hectares is termed the "Observed Merchantable Mortality Area" (OMMA).

OMMA is not necessary for the purposes of computation. However, it is a useful concept in interpreting the results of this study in the context of tree mortality on areas where the mortality actually occurred. The casual observer is conscious of the sprayed areas that exhibit dead trees and of the number of dead trees on those areas. He is not so conscious of the areas sprayed that show no dead trees. Mortality in terms of OMMA reflects the impression that an observer obtains when he views the inland forests of SVN from an aircraft over-flight. Many areas that were sprayed during the herbicide missions now show no visible merchantable trees. Hence a value for the ratio of dead trees to total sprayed area even though it is correct will seem to be very low when it

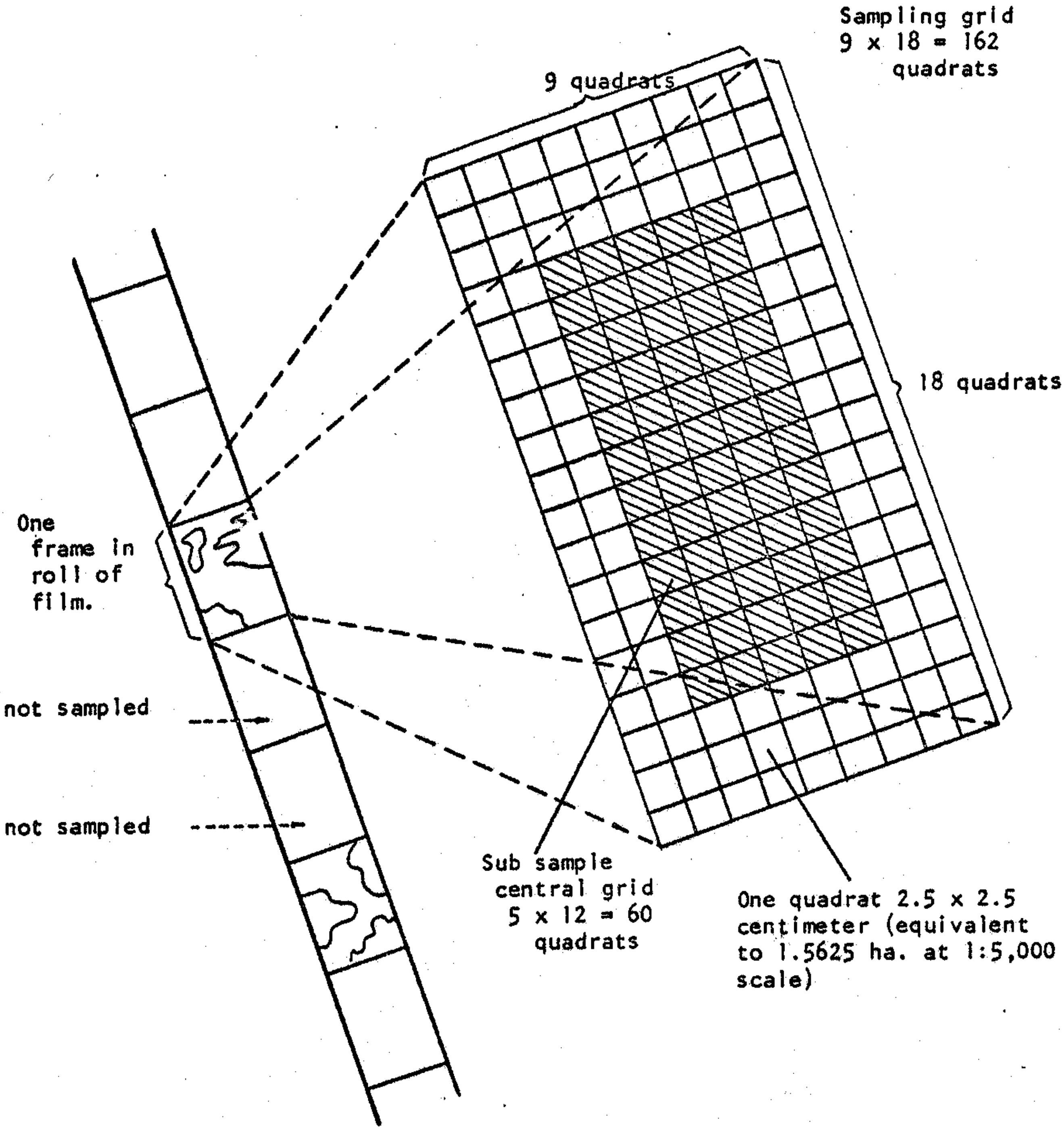


Fig. IV B-28. Sampling technique used in tree counting. Each third frame of the film (left) is placed over a grid with 9 x 18 = 162 quadrats. The relative area of different forest types is based on count of quadrats per type throughout the whole (162 quadrat) grid. Dead merchantable trees were counted in all quadrats within the 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 third photo frame.

Table IV B-5

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

is considered by an observer who has been examining locations where damage is very great and dead merchantable tree frequency is high. Dead merchantable trees per OMMA ha was used in discussion to make the data more meaningful to an observer with such an experience.

In Table IV B-6 are listed the number of quadrats having 0, 1, 2, etc. dead merchantable trees for 25,680 quadrats. In Table IV B-5 is a summary of the dead tree statistics. It should be noted that dead tree counting proceeded <u>over the entire sample area</u>; it was not limited to areas recorded as having been sprayed. Hence no calculation is given, at this point, for dead trees relative to area sprayed.

<u>Computation of Damage to Merchantable Timber</u>

The first computation procedure bases the damage estimate on the dead tree count within each type of forest over the entire sample area. The following are the essential steps in calculation:

(1) Est. total dead merch. trees in all sprayed SVN inland forests

$$= \text{Total dead trees in sample} \times \frac{\text{Sprayed area of SVN forests}}{\text{Sprayed area within sample}}$$

$$= 9{,}844 \times \frac{1.08 \text{ million ha}}{11{,}195 \text{ ha}}$$

= 950,000 trees (all species)

(2) Est. total dead merch. trees in forest type in all SVN (e.g., #1)

$$= \text{Total SVN dead trees} \times \frac{\text{Number of dead trees in forest type in sample}}{\text{Number of dead trees in all forest types in sample}}$$

$$= 950{,}000 \times \frac{264}{9{,}844}$$

= 25,500 trees (all species) in forest type #1

Process repeated for all forest types.

(3) Est. total dead volume of merch. trees of merch. species in a forest type in SVN = Sum, for each of 3 tree size classes, of est. dead merch. trees in forest type

x [fraction of trees in tree size class

x fraction of trees of merch. species in the size class

x average merch. volume per tree in the size class].

Process repeated for all forest types.

Table IV B-6

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

The sum of the total merchantable volumes for all forest types is the estimated total damage. The computations were conducted for the area of MR III alone and for the whole of SVN. The results were:

MR III	All of SVN
725,000 m^3	1,245,000 m^3

Considering the variation inherent in the sampling and in the counts and measurements it is the judgment of the Committee that the damage to merchantable timber is within a range of 0.5 million and 2 million cubic meters. A discussion of the sources of variation as they are related to the damage estimate follows.

Discussion of the Estimated Merchantable Volume Damage

Calculations to this point have been based upon the assumption that all of the dead volume of merchantable trees was due to herbicide treatment. Clearly this is not reasonable. Normal mortality is a common phenomenon in multi-aged forests. The structure of the forest evolves from a continuing mortality in each age class resulting in the familiar J-shaped curve which emerges from the plotting of tree frequency as a function of tree diameter. This mortality rate varies depending upon the forest type. A generalized forest structure curve for the forests of Southeast Asia of the sort represented in this study shows that the tree numbers in a particular size class of trees is reduced by a factor of about three as these types move over an average diameter increase of 20 cm.

That is to say, the number in the 40 cm diameter class is about one-third the number in the 20 cm diameter class. Thus for every 30 trees that have a 20 cm diameter at any given time only 10 will survive to become 40 cm in diameter. This process goes on throughout the range of diameter classes represented in a stand. Thus normal mortality results in dead trees. Those of small size decompose rapidly and disappear. Those of large size decompose much more slowly and remain as visible snags for a number of years. Clearly the dead tree count would include some of those trees. Other trees were killed by bombing, shelling, burning and logging and these too would have the effect of inflating the expectation of herbicide kill. It was not possible to remove all of this non-herbicide related mortality. Given the pattern of herbicide application it was attempted to make a judgment concerning the contribution of normal mortality to the dead tree count. An estimate not described here was based upon a study of forest areas in SVN included in the sample areas studied but remote from any area recorded as sprayed. These areas show the pattern of isolated dead trees typical of normal mortality and are quite different in their appearance from forests known to have been sprayed and showing heavy mortality (Fig. IV B-29).

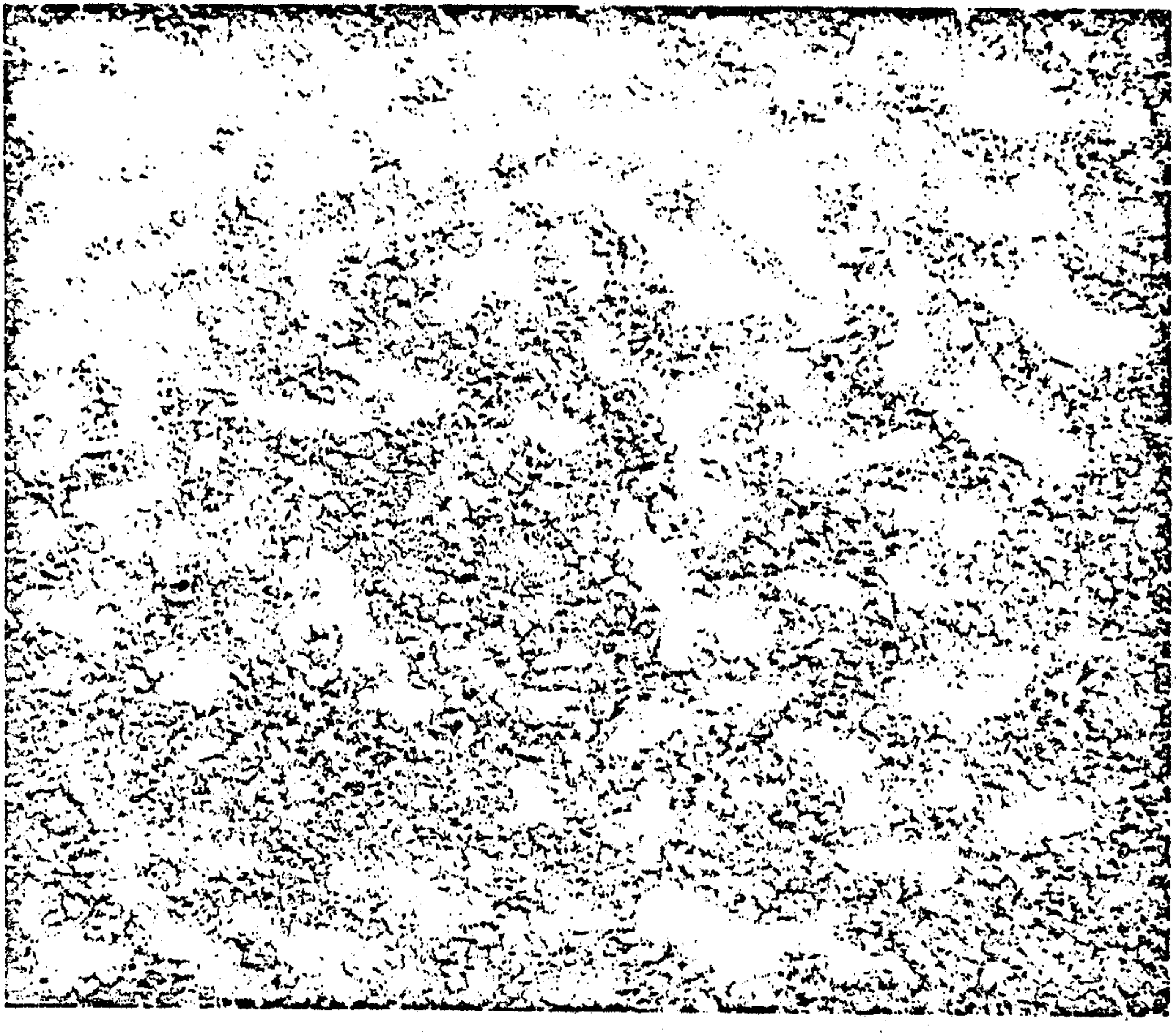


Fig. IV B-29. Area of forest not treated with herbicide. Some dead trees are visible. This background mortality is due either to natural mortality or to human activities.

Logging on an economic basis, a very common practice in SVN, leads to the occurrence of a disproportionate number of large non-merchantable trees in the upper canopy of the forest. They are either trees of non-merchantable species or specimens of merchantable species that are non-merchantable because of major defects. These trees can grow to large sizes because they are regularly disregarded in normal timber harvesting operations because they are not useful for lumber and plywood. They are also passed over by farmers searching for fuel since because of their size they are difficult to fell for individuals equipped only with axes. As a result these trees grow to very large sizes before dying a natural death and because of their size they commonly remain visible as standing hulks for a long time. In his study of the Cambodian inventory, Rollet (1962b) eliminated all trees over 130 cm in diameter on the basis that they were large trees of this non-merchantable kind. In addition to the substantial contribution which the large non-merchantable trees make to the background of normal mortality they also contribute to overestimating the merchantable loss in sprayed areas since, as large emergent trees they occupy a very vulnerable position in the upper canopy of sprayed stands.

A second important cause of dead trees in SVN was bombing and shelling. Areas photographed soon after bombing show much tree mortality outside of the immediate hit zone. Examination of photographic sequences over a number of years indicates that rapid revegetation tends to quickly convert the area to a broken forest without visible evidence of the individual bomb strikes but with swaths and pock marks covered with small trees and shrubs. The areas surrounding these openings often contain dead trees that were severely damaged but not totally destroyed (Figs. IV B-18 through B-21).

Apart from tree mortality not caused by herbicides, a number of other factors can affect the accuracy of the various elements in estimates of merchantable timber losses. The computations discussed above depend for their accuracy on the accuracy of the individual separate figures used to obtain the final answer. In Table IV B-7 is a list of possible factors which may have affected the estimates. This list is not complete but includes the important factors.

One of the major elements in the computation is the count of dead merchantable trees. As the table indicates this count can be affected by a number of factors, some causing an overestimate, some an under-estimate; where the same factor could lead to one or the other it is listed in both columns of the table. For example, errors of measurement or of judgment of size of trees could lead to either over or underestimation. Before discussing this question further it is appropriate to note some relevant facts about the determination of the minimum merchantable size of trees. For standing trees, the most generally used measure of size is diameter at 1.5 m above ground (or at the top of buttress in trees having that characteristic) referred to as dbh. The most direct evidence of what minimum diameter is accepted on the market is data from factory log yards.

Table IV B-7

Possible Factors that may have Affected the Estimates of Damage

Parameter	Effect of Factors on Estimates of Herbicide Damage to Merchantable Timber	
	Overestimate	Underestimate
A. Count of dead merchantable trees killed by herbicide	1) Trees dead; trees seen by observer	
	- size misjudged - diameter limit too low (dead trees at low end of distribution) - film scale fluctuation - stem covered in vines - death not due to herbicide - dead tree not merch. species - dead tree not merch. quality - dead tree part rotted before spraying	- size misjudged - diameter limit too high (dead trees at high end of distribution) - film scale fluctuation - stems covered with vines - crown decayed to smaller diameter
		2) Trees dead, present, but not seen by observer
	3) Trees seen, not actually dead	
		4) Trees dead but absent (cut or rotted)
		- trees cut and salvaged are not considered a loss - trees rotted are loss if of merch. species, otherwise not
	5) Sampling	
	- sample areas overrepresent heavy damage	- sample areas over-represent light damage
	6) Natural mortality	
	- no correction made	- not applicable

Table IV B-7 (cont'd)
Page 2

Parameter	Effect of Factors on Estimates of Herbicide Damage to Merchantable Timber	
	Overestimate	Underestimate
B. Total number of hectares of forest sprayed	1) Mission records	
		- areas sprayed but records missing - faulty records omitted from analysis
	- compensation for mission records assumes no overlap - actual spraying in different location than recorded	- actual spraying in different location than recorded
	2) Spray swath width	
	- actual width less than nominal 80 m	- actual width greater than nominal 80 m
C. Number of hectares of each type of forest within sprayed area of whole country	1) Sampling	
	- sample area over-represents non forest and low merch. volume forests	- sample area over-represents high merch. volume forests
D. Total number of hectares sprayed within area sampled	1) Location of spraying	
	- actual spraying in different location than recorded	- actual spraying in different location than recorded

Another important element in accuracy of dead tree counts is the measurement and judgment of tree size. As previously described, dead trees were counted from a sampling area subdivided into quadrats (2.5 by 2.5 cm) each equivalent to 1.5625 ha of land area at film scale 1:5,000. It is important to realize the magnitude of the tree count sampling. A total of 33,830 sample quadrats was inspected; on these a total of 9,844 dead merchantable-size trees were observed. A summary is presented in Table IV B-6 of the number of quadrats found to have 0, 1, 2, 3, etc. trees within the subsample of 25,680 quadrats; these frequencies are listed both by forest micro-type and for all forest types together. It is obvious that, while counts of 10 or more dead merchantable-size trees were recorded, the majority of the counts were lower. In fact, the average count per quadrat having at least one dead tree is 1.883 (equivalent to 1.205 trees per ha within areas having at least one dead tree). This dead tree count was made on photographic film of scale stated as 1:5,000. Reference trees of 45 cm. dbh and others of crown diameter 10 m were located by precise micrometer measurement on reference photographs used by the observers to judge, on other frames, whether dead trees were larger or smaller than those representing the minimum merchantable size. Initially the observers used the stereoscope frequently, but once they were well practiced, the stereoscope was used only intermittently for quality control purposes and to check in doubtful situations. This practice was followed for two reasons; first, the magnitude of the sampling job precluded use of stereo throughout; second, at 1:5,000 scale a 45 cm tree appears as a line of just less than 0.1 mm width which is quite readily visible except when the tree is covered by vines or hidden in the shade of other vegetation. In general this can happen only if the tree crown has rotted or broken off and only a crownless stump or "snag" is left standing. The higher the probability of such rot or breakage, the less is the likelihood that the tree was of a merchantable species since durability and merchantability are closely related. (On the other hand, if a dead tree is covered with vines and clearly visible its size may be overestimated. Thus, covered trees appear in Table IV B-7 as a potential factor for both over- and underestimate.)

It should be noted that differences in tree counts between observers would not be reflected in proportional differences in tree volumes. Below is an example of a stand table for an all-aged multi-species forest in Southeast Asia (Rollet, 1962b) to which has been added crown sizes, tree volumes (i.e. merchantable volume) and stand volumes based upon criteria used in this study:

Dia. Class Breast Hgt., cm	120+	110	100	90	80	70	60	50	40	30	20	Total
Crown dia. m^3	30.0	27.2	24.5	21.5	18.9	16.2	13.5	11.0	8.7	6.4	4.0	
No. of trees/ha	1	1	1	2	3	3	7	10	16	36	75	155
Vol./tree m^3	4.2	3.9	3.6	3.1	2.6	2.0	1.4	1.0	0.7	0.4	0.2	
Stand vol. m^3	4.2	3.9	3.6	6.2	7.8	6.0	9.8	10.0	11.2	14.4	15.0	92.1

When the trees killed by herbicide are large, it is unlikely that the decision of whether or not to tally it would be the subject of debate among observers, its crown, dead or alive, would dominate the overstory. As large trees they would not disintegrate in a few years nor would they be completely covered by vines or be otherwise obscured.

The larger, upper canopy trees are represented in the stand table above by the upper portion of the diameter range. The important point concerning proportionality can be grasped by noting the following: the largest tree (120+ cm) represents 0.6 percent of the number of trees above 20 cm dbh, but 4.6 percent of the stand (total volume), the 3 largest trees together make up 1.9 percent of the number but 12.7 percent of the volume. Thus, the smaller the trees, the greater their number but the less the percent of total volume added per additional tree.

Arguments over the admissability of dead trees will occur at the margin of minimum size where tree numbers are large but tree volumes are small. The following tabulation indicates the relation between tree numbers and tree volumes assuming that a 40 cm dbh tree is the minimum tree size standard and assuming observers differ by 50 or 100 percent in either direction from the standard in counting numbers of trees.

Effects of Tree Counting Errors on Volume Estimation

	Values at 40 cm Standard	Counting Trees Smaller than Standard (Overcount)		Missing Trees Larger than Standard (Undercount)	
		50%	100%	50%	100%
Number Trees counted	44	66	88	29	22
Est. stand volume[a]	63 m^3	73 m^3	80 m^3	53 m^3	46 m^3
Volume % error from standard	--	16	27	16	29

These figures indicate that a difference between observers even as great as 100 percent at the tree size margin would have an impact on volume of less than 30 percent and that smaller counting differences would cause even lesser differences in the estimated volume.

[a] Obtained by interpolation from graph of cumulative stand numbers and volume.

It should not be inferred from this example that equally qualified observers using the same criteria for counting would differ by factors as great as 50 or 100 percent. Differences in tree counts among observers used by the Committee were in fact very much less than this.

The importance of this example is that it illustrates that while misjudgment of tree size can be regarded as a random error (i.e., observers can default in either direction), the effect of overestimating the number of dead trees implies counting trees of smaller than average merchantable volume. Higher tree counts for this reason do not lead to proportionally higher merchantable volume. Since the minimum merchantable diameter is already assigned the smallest reasonable value, rather than an average figure, it is considered that the tree counts are, if anything, on the high side.

As indicated by the equations used in computing the damage estimates, the volume of dead merchantable trees is computed by first subdividing them according to size class, and then multiplying the average volume per tree in the size classes by the number of dead trees in the respective size classes. Average volume per tree differs considerably, hence it is important that the subdividing of total number of dead trees into size class subtotals be done correctly.

Murray and Vaughan (1969) studied aerial herbicide applications in hardwood forests in Thailand and evaluated them for maximum effect and minimum drift. As a result of these experiments they concluded that "only a very small percentage of the total spray will actually penetrate the canopies and that only the top and peripheral areas of the vegetation will be contacted by the herbicide." Since spraying first affects the upper canopy trees, it is to be expected that where only a few trees are killed these would be upper canopy trees. The question then becomes, "What sizes of trees are present in the upper canopy?" A special study was conducted to analyze the size distribution of dead trees, and how it related to size distribution of all trees. The results established clearly that over the whole size range of merchantable trees, the dead tree distribution is indistinguishable from that of all merchantable size trees. This implies that the death of trees is random with respect to size and, therefore, is evidently a function of species, health, etc. Hence, the fractions used in the equations, which were derived from total merchantable tree size distribution, are correct for the purpose of estimating dead merchantable volume.

The scale of aerial photographs is determined by the focal length of the camera, a factor which is fixed, and the height of the aircraft above the ground being photographed, which varies both because of the topography of the ground and variations (rise or fall) in height of the aircraft. The intended scale of the films used in dead tree counting was 1:5,000. Each film was sampled for scale at several points over its length. The average scale for all films was 1:4,975; this is very close to the nominal value, and variation around this mean scale generally did not exceed ± 4 percent. The effects of scale being smaller than 1:5,000 (e.g., 1:5,200) are: (1) the actual land area equivalent to the 2.5 by 2.5 cm sampling quadrat is greater than the 1.5625 ha assumed in the analysis, and (2) tree sizes based on an assumed scale of 1:5,000 are less than they are in reality. The first effect leads to the estimated number of dead trees per ha being greater than they are in fact; the second effect leads to undercounting the merchantable dead trees. Effects of the scale being smaller (e.g., 1:4,800) than assumed are opposite. Since the scale fluctuations were generally small and in both directions, their combined effect was considered negligible and no adjustment was made in the tree count figures.

Mission Records

The quality of these records is discussed in Section III C(1). Two points are of major concern, namely mislocation of missions and missing records.

Where the area sprayed differed in location from the one given in mission records, the "area sprayed within sample" would be affected if the mislocation moved the spraying out of or into the path of the sample area photographed. However, there is no basis for assuming a greater tendency in the one or the other direction and the error can be considered to be random.

An estimate of missing records is given in Table III C-1. The consequence of records being missing is that the area sprayed would be greater than assumed. However, since the sampling pattern is random with respect to spraying it is reasonable to assume that both the "total area sprayed in SVN" and the "area sprayed within sample" would increase in approximately the same proportion if the area for which records are missing were added to the data bank. Since these two figures are used in a ratio, an equal proportional change in both would leave the ratio unchanged; hence, no attempt was made to adjust for missing records. The key figure in the computation is the total number of dead merchantable trees; since these were counted wherever they occurred, and not only where the records indicated spraying, it is considered that missing records have not invalidated the estimate to any serious extent.

Because of wind and turbulence caused by the aircraft itself the spray may spread more or less widely than in calm air, or may in extreme cases be displaced wholly from the area vertically below the aircraft. While it is possible that for these and other reasons the spray swath may be wider (or narrower) than the nominal 80 m, the general pattern of spraying must be noted (Section II B).

Most of the herbicide was applied in missions placed in parallel arrays. Increase or decrease of swath width in areas so treated would simply tend to miss or fill along the adjacent borders of these missions. Clearly these fluctuations could lead to overlap of treatments but only at the expense of dilution in the intended spray target area.

Frequency of actual as compared with recorded application could be affected by fluctuation in spray swath width so that some areas thought to have been sprayed 2 times, for example, might in fact have been sprayed 3 times, or only once. These errors would tend to be random and would balance out. Thus, they do not influence the assessment of damage.

Adequacy of Sampling

The Committee decided early in its deliberations that it was essential to use low elevation, up-to-date aerial photographs as samples for damage assessment purposes. Originally, thirty-five areas were selected to be photographed as samples. This selection was made on the basis of the only information and material available to the Committee at that time, namely printouts of the herbicide operations from the HERBS tape, and the Rollet vegetation map. The selection was made so that the sample areas would be representative both of impact (spray) frequency and of the Rollet forest types. Another consideration was to have them easily identifiable by some prominent landmarks. However, upon presenting the list of these samples to MACV we were advised that photo coverage of this number of small spots was too hazardous. Accordingly a new system of aerial photographic sampling was devised involving the use of long strip samples. These were selected to permit coverage comparable to that sought in the original sampling scheme. The strip sampling method gave a much larger sample than would have been obtained using the small area samples originally planned but was somewhat more restrictive in terms of the number of independent locations provided. The strips were flown twice, in the wet and the dry season (October 1972 and January-February 1973, respectively) but the overlap was far from accurate so that the actual sample area was almost doubled. On many of the flights back-up black and white photographs were also taken. This extensive coverage and duplication permitted the rejection of photographs whose quality made assessment difficult without jeopardizing the size or representativeness of the sample. A map of the photographic strips used in sampling is given in Fig. IV B-30. The figure shows how the 16 rolls of film coverage are located in relation to the sprayed areas in MR III. These modifications substantially increased the size of the sample but somewhat changed the original sampling plan, 23 of the originally selected 31 sample areas (26 percent) being excluded from the new sample flight lines.

The representativeness desired in such a sample is that it provides an adequate, proportional sample of the various types of forest

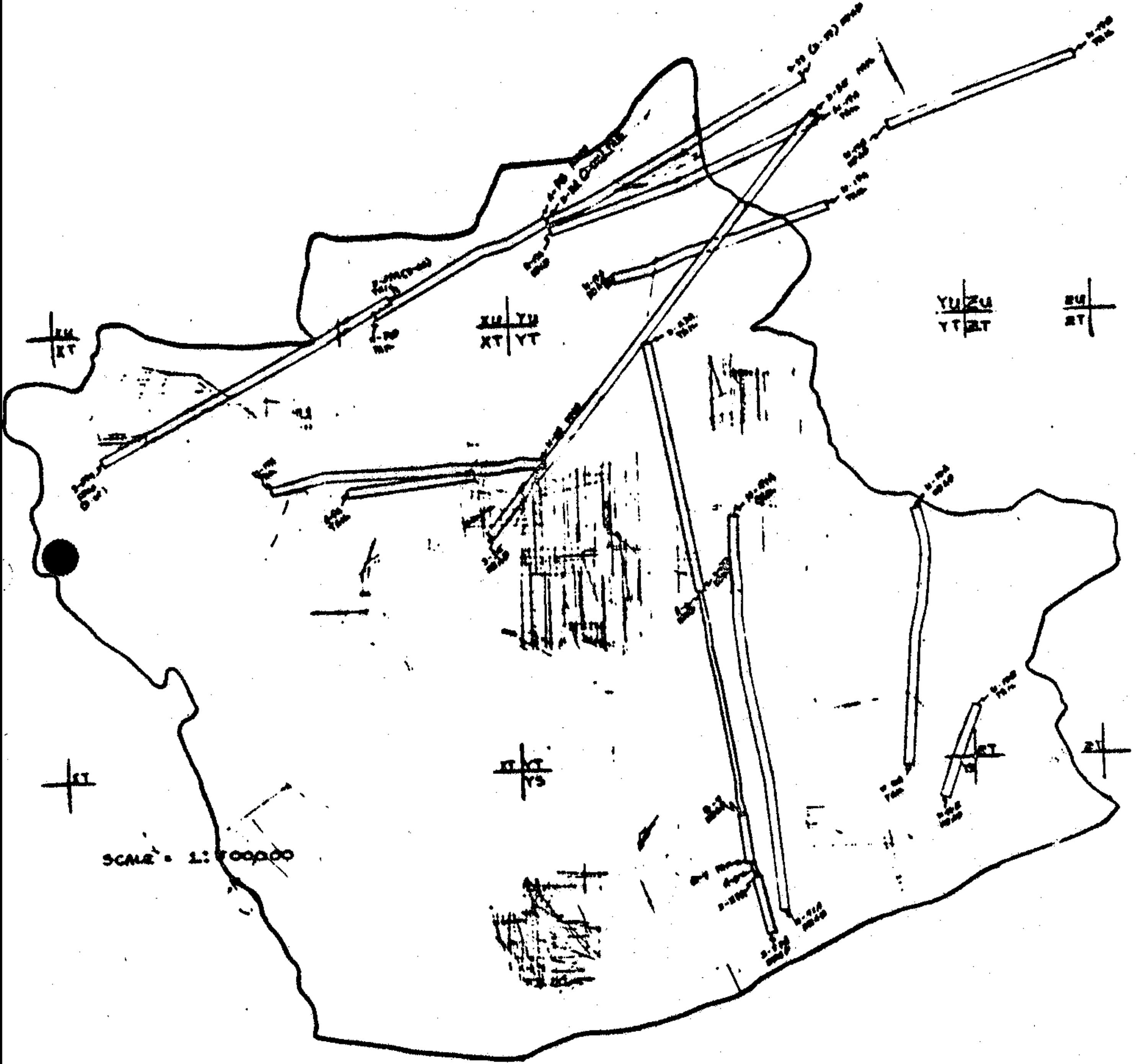


Fig. IV B-30. Map showing location of XT and YT quadrangles and the 1:5,000 scale photo samples in MR III. Lines indicate paths of defoliation missions from 1965 to 1971.

and of the degrees of damage associated with these. An analysis of the sample coverage with respect to forest types and frequencies of spray impact indicated that the samples were representative of the forests being sampled within limits acceptable in forest inventory practice.

Inventory of Non-Merchantable Volume

It is obvious from aerial photographs that much of the damage in the forests was in trees of smaller than merchantable size. An inventory of the non-merchantable volume was developed to provide a basis for assessment of damage to that component of the inland forest.

While the merchantable volume was inventoried in some detail by sampling aerial photographs for data on each forest type, the non-merchantable volume was estimated in a more appropriate way. The reasons for this are outlined below.

In Fig. IV B-31a-c are given vertical correction, or profile, diagrams representing a tropical hardwood forest. The shaded portions in Fig. IV B-31b boles (tree #1-4) represent merchantable size material of merchantable species. The merchantable stem segments are shown separately in Fig. IV B-31c to emphasize their relation to the whole stand.

The non-merchantable volume of the stand includes:

a. the boles of trees of merchantable size but not-merchantable species.

b. the stems of all trees smaller than merchantable size, of both merchantable and non-merchantable species.

c. the branch wood and stem tops of all trees of all sizes and all species.

If the procedure used in the inventory of merchantable volume was followed, it would be necessary to count the non-merchantable size trees (diameter less than 45 cm) in sample aerial photographs. This is not feasible because the smaller, more numerous crowns are too difficult to separate from one another even in a completely visible crown layer. Further, many of the smaller trees, in some types of forest, are located directly under the larger tree crowns and hence not visible in aerial photographs.

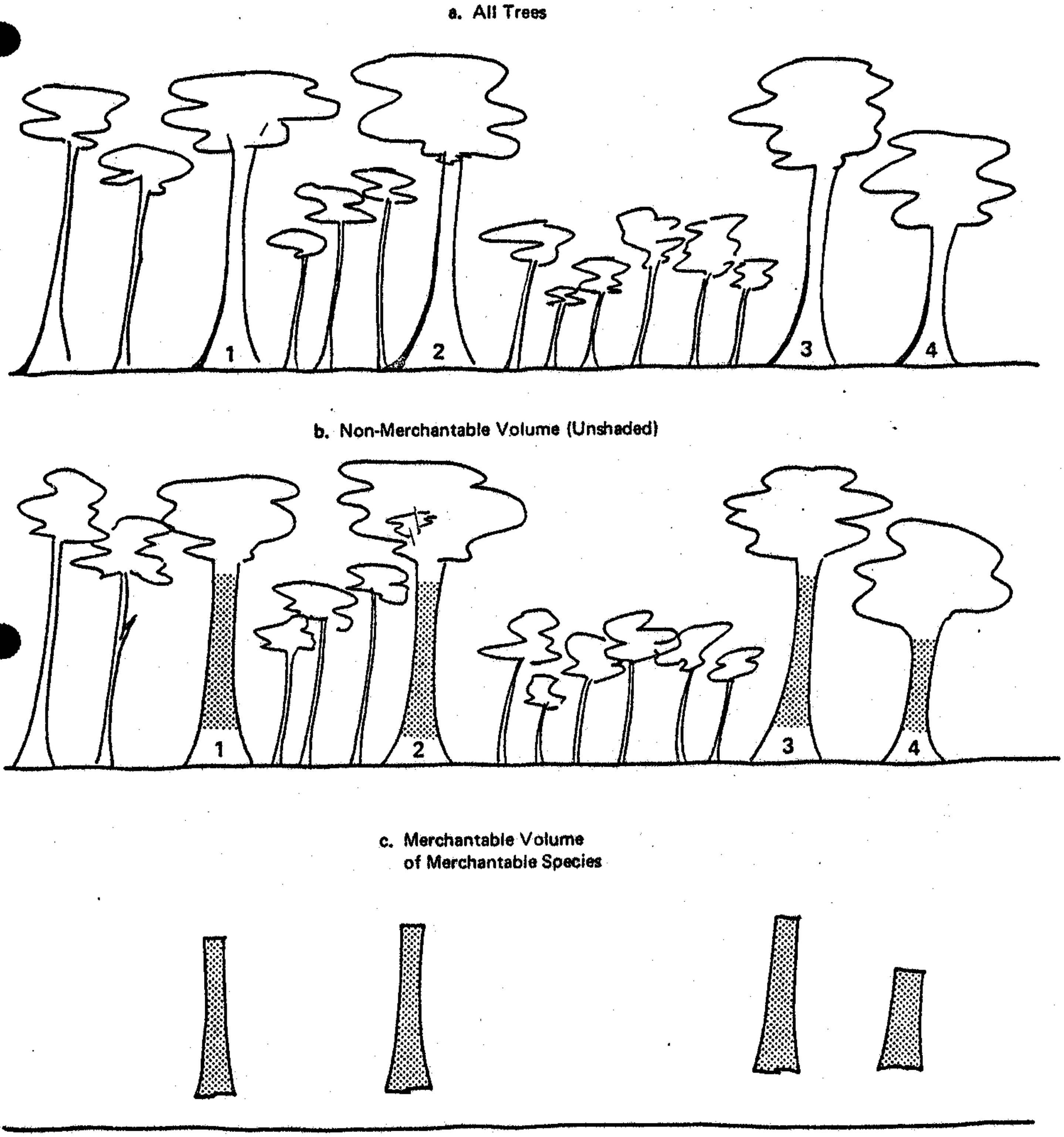


Fig. IV B-31. Profile diagrams of a tropical hardwood forest showing merchantable volume of merchantable species.

The procedures used, in brief, were as follows:

a. Volume of stems of merchantable size but non-merchantable species and quality was computed by employing the equations already given, but with fractions for the non-merchantable species and quality substituted in place of those for merchantable.

b. Volume of stems of smaller than merchantable size was estimated by analysis of forest biomass data from plots in Thailand and Cambodia, since none were available for inland forest in SVN.

c. Volume of branch wood was derived from relations between stem weight and crown (branch and top) weight of many individual tropical hardwood trees in Thailand and Cambodia, and similar data, but in terms of volume, for sample trees in Central America and Puerto Rico. The percentage relation between branch wood and stem wood for individual trees was applied to the total stem wood volumes for merchantable and non-merchantable size trees to estimate total branch and top volume.

The data for (b) above came from published analysis of biomass plot data from Cambodia (Rollet, 1962b) and from plots already established in Thailand plus others established for the Committee by faculty and staff of the College of Forestry of the University of Kasetsart, Bangkok, Thailand. The plots in Thailand were chosen to represent Moist Evergreen, Dry Evergreen, Dry Dipterocarp and Tropical Rain Forests. On these one hectare plots every tree of one inch diameter and larger was tagged, mapped, measured for diameter and height and its species identified. Analysis of these data gives excellent figures for the most dense parts of the forests which these plots represent, since they were carefully selected to give that representation. Regional inventory figures for Northeast Thailand were then 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, averages were estimated for all SVN forest types together, as follows:

	Tree Diameter Range (cm)			
	0-15	15-30	30-45	All
Number of stems/ha	400	60	20	480
Stem wood volume m^3/ha	4	3	10	17
Crown wood volume m^3/ha	2	1	4	7
Total non-merchantable volume m^3/ha				24

These figures correspond to roughly half the values for the trees below 45 cm diameter in the dense Dry Evergreen forest plot in Thailand and one-fourth of the non-merchantable component of the dense Moist Evergreen forest sample plot. However, the number of stems in these sizes are approximately equal to the regional inventory average across both exploited and unexploited forests in Thailand. Since the approximately one million hectares of inland forest sprayed in SVN include forest types, most of them actively exploited, ranging from the closed forest without brush, to extensive forests with substantial brush and areas of essentially non-forest vegetation, it is considered that the averages given above are appropriate to apply in approximating non-merchantable volume for the entire one million sprayed hectares.

It should be understood that while, for example, the average volume of non-merchantable stems is 17 m^3/ha, denser forest types may contain 50 m^3/ha while the most sparsely stocked forests (e.g., recently abandoned shifting cultivation areas) may contain as little as zero m^3/ha of non-merchantable volume. Similarly, the number of trees of diameter 30-45 cm (about 12-18 in) may range from 60 or more down to zero within the range of forest types.

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 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 decomposed 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. Table IV B-8 indicates the Committee's estimates of non-merchantable portions of the forest. Since they must be based upon assumptions that cannot be verified, high, medium and low estimates are given. It is the Committee's judgment that the

Table IV B-8

Estimates of Non-merchantable Wood Damage
(millions cubic meters)

	Range of Estimated Damage	
Component	Upper (m^3)	Lower (m^3)
Merchantable size stems of non-merchantable species	.75	.25
All non-merchantable size stems	7.00	3.00
Crowns of all trees merchantable and non-merchantable	3.40	1.80
Total non-merchantable forest components	11.15	5.05

damage to non-merchantable components is within the range of 5 to 11 million m^3 of tree components. The median of this range is about 8 million m^3. Branch wood in crowns represents about 30 percent of total non-merchantable wood loss. 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 overstory 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 70 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 some 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 grow under these cover crops and eventually emerge from them to produce a multi-species multi-aged forest. A study made by Dr. 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 6 to 26 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 probable 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 should be understood that while the loss estimate ranges from 20 to 40 percent of the total non-merchantable volume on the average over one million ha, individual stands could be damaged considerably more or less than this average.

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

The Directorate of Water and Forest of RVN (Director of Water and Forest, 1971) reported a damage of fuelwood quality forest material of 7,583,094 steres[a]. This is roughly the equivalent of 4,500,000 m^3. 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 in SVN.

Interpretation of Damage Assessment Results

It is obvious from the preceding discussions of accuracy and its limitations that many possible factors may influence estimates of damage to merchantable timber. This is well known in forest survey practice and measures have been developed to minimize those factors. These steps and an extra measure of care were exercised in this assessment of loss of merchantable timber in SVN. The greatest source of error lies in sampling; the areas chosen may by chance provide estimates of overall mean damage higher or lower than the true mean. This error can be reduced either by increasing the size of the random sample, or by adopting a different design of sampling, including checks on the ground. The latter was not feasible under the conditions of this study, but our sampling of the forests of MR III would be considered more than sufficient in routine forest surveys. The Committee's estimate, according to which the total loss of merchantable timber is within the range of 0.5 million cubic meters and 2 million cubic meters, allowing for sampling errors and various factors discussed above, is in reasonable agreement with an estimate of merchantable timber loss due to herbicide treatment made by the Directorate of Water and Forest of RVN mentioned before and based upon reports from provincial Forest Services and/or Districts. This figure is 1,464,888 cubic meters, and it refers to the timber loss in forest area managed by the provincial Forest Service which is 5,908,793 ha. This includes mangrove forests and *Melaleuca* woodlands, which, however, contribute little if anything to merchantable timber. The loss figure is based on the amount of wood usually exploited per year without considering other, unexploited species of wood, i.e. represents the merchantable volume. Using different utilization standards, the Director of Water and Forest of RVN in the above mentioned document considers the loss figures an underestimate.

Earlier estimates of unsalvageable damage to the inland forests were expressed in terms of merchantable timber volume. Among these early estimates the most frequently quoted were those reported by Flamm (1970) and Westing (1971). While the Flamm and Westing studies were reported independently they are in close agreement on the volume of merchantable timber lost through herbicide treatment and not salvaged Flamm estimates the loss to be about 46 million m^3 and Westing about 45 million m^3. Since these estimates were so large relative to the size of the country and the area of its forest, they have become a focal point for public concern about the damage caused by herbicides, particularly the inland forests in SVN, and have been widely reported and accepted in the U.S., SVN and indeed throughout the world. Essentially no factual data were presented by the authors to substantiate

[a] 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.

their estimates of damage. Rather these estimates were based upon certain assumptions concerning the pre-treatment status of the forests and the effect of various levels of herbicide treatment. These assumptions were:

1. Inventory of Affected Forest. Both Flamm and Westing assume that the average merchantable volume of the inland forests of SVN affected by defoliation treatment was 100 m^3 per ha (40.47 m^3 per acre).

2. Area Treated. Flamm assumes that 1.35 million ha of forest were sprayed, 900,000 ha treated once and 450,000 ha more than once. Westing's figures are 2,000,000 ha, 1,500,000 ha, and 500,000 ha, respectively.

3. Growth Rate. Flamm assumes a growth rate in terms of merchantable volume of 0.5 m^3/ha/yr. Westing's assumption for the same parameter is 1.0 m^3/ha/yr.

4. Standing Merchantable Timber Damage Not Salvaged. Flamm assumes a non-salvageable loss of merchantable timber on areas treated once to be 15 percent; on areas treated more than once, 75 percent of merchantable inventory. Westing uses the figures of 10 percent and 60 percent, respectively.

5. Growth Loss. Both Flamm and Westing undertake to estimate loss of growth caused by temporary defoliation with subsequent recovery. For areas treated once Flamm assumes a 20 percent reduction in growth for ten years, for areas treated more than once a 75 percent reduction in growth for ten years, followed by a 50 percent reduction for an additional ten years. Westing assumes that "the average recovery time for a depleted stand is 15 years..."

Even allowing for the lesser precision in estimating the damage in the forest of MR I and II it is clear that the Committee's assessment of merchantable timber loss is of the order of one to four percent of that of Flamm and Craven (1972) or Westing (1971). Since these authors used Class II timber prices in computing their estimates they were presumably using lumber and plywood utilization as a merchantability basis.

The very high values obtained by these earlier observers derive from certain errors in their assumptions. The most important among these are the following:

1. The average merchantable volume of the inland forests was grossly overestimated, apparently because these observers were unaware of the extent to which the forests had been exploited previously in various ways.

2. Rollet's (1962b) estimate of growth rate for comparable Cambodian forests is 0.33 m^3/ha/yr, that is, two-thirds of that assumed by Flamm and one-third of the assumption of Westing.

3. There was no threshold of extreme damage at two applications of herbicide as postulated by the earlier observers. Damage varied progressively from very light with one application to very heavy with more than four applications (Fig. IV B-32).

4. A common form of evaluation used in earlier studies was to observe damage where it was known to have occurred but not to make observation in areas known to have been sprayed but where damage was not apparent. This system of sampling resulted in overestimation of damage.

It should be noted that there are some anomalies in the damage evidence. In a small area of the YT quadrangle south of Dong-Xoai and near the abandoned Rang Rang Air Base there are several strips of forest from which the tree cover has almost entirely disappeared. Fig. IV B-33 illustrates this area. Cleared strips such as this commonly coincide geographically with areas where four herbicide missions were flown. Other areas impacted as many or more times did not exhibit this much damage. Furthermore, study of photographic sequences over time indicated that the forest was essentially present after the first three herbicide exposures and then largely disappeared following the fourth one. The timing of the treatment with respect to season and to prior treatment can be expected to have had an important influence upon the herbicide effect. Information necessary to test this hypothesis was available to the Committee, but time did not permit us to conduct the analysis. It should, however, be noted that such areas of almost total removal of the tree cover represent only a very small fraction of the sprayed inland forest areas.

Estimation of Economic Loss

The monetary value of the damage to the forests of SVN due to herbicides was estimated by Flamm and by Westing by multiplying the lost timber volume by an assumed stumpage[a] price in piasters and converting it to U.S. dollars at the official rate of exchange (VN $118 = U.S. $1). Obviously, this monetary value, which Flamm estimated to be $490,000,000 for dead merchantable standing timber is greatly inflated because of his overestimate of merchantable timber. It is, however, also a questionable economic analysis in several other respects, even if the damage had been estimated correctly.

Determination of an appropriate and reasonable stumpage value is an important problem. In undertaking harvest of timber from forests

---

[a] Price of standing timber before it is cut.

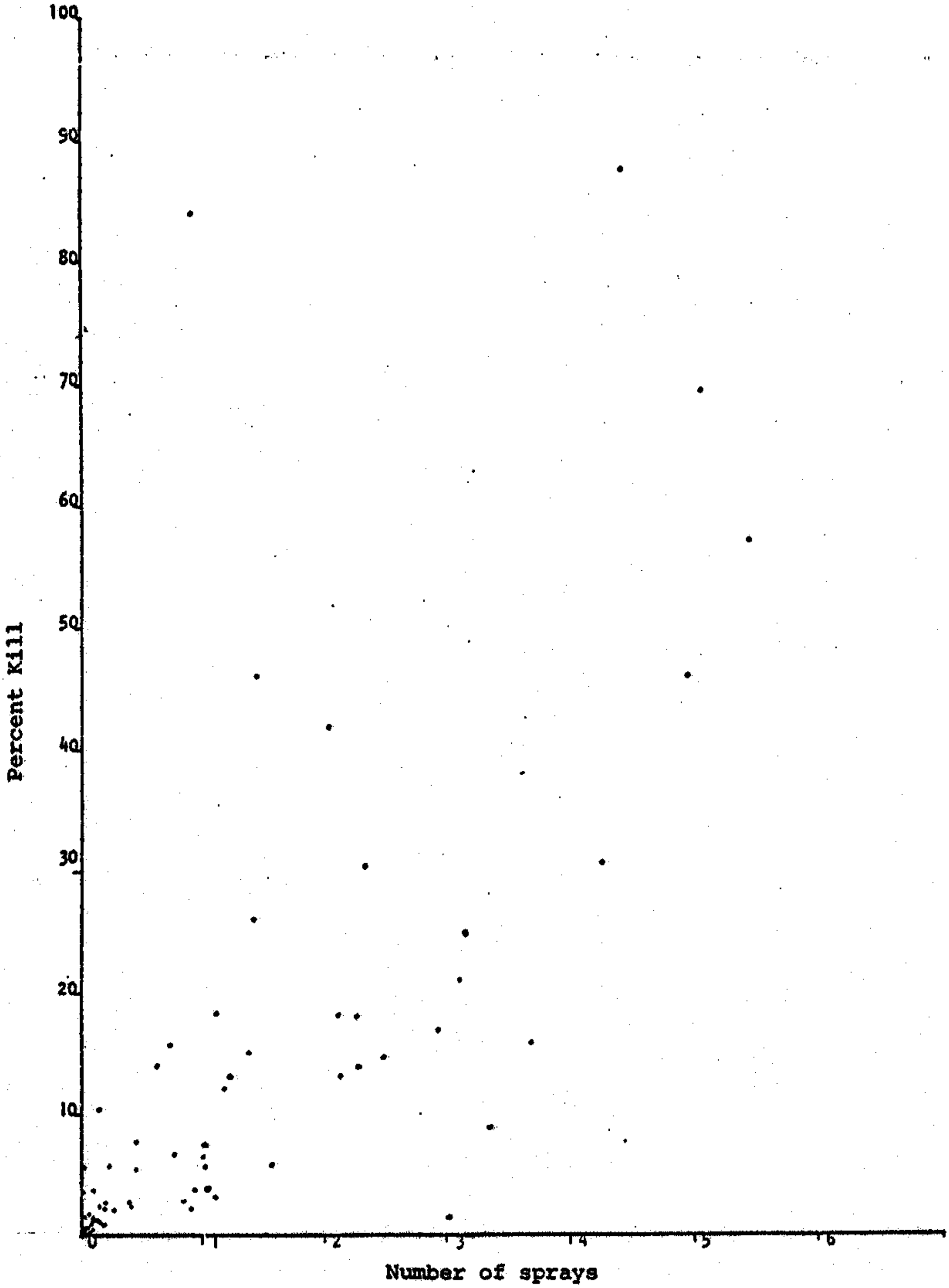


Fig. IV B-32. Distribution of mortality of merchantable size trees as a function of spray frequency. Each point represents a sample area of one photographic frame. It was not possible to find enough sample areas sprayed with uniform spray coverage (0-1-2-3 etc.) therefore areas were selected in which one spray number predominated, but the <u>average</u> spray number of the same area was used in the figure.

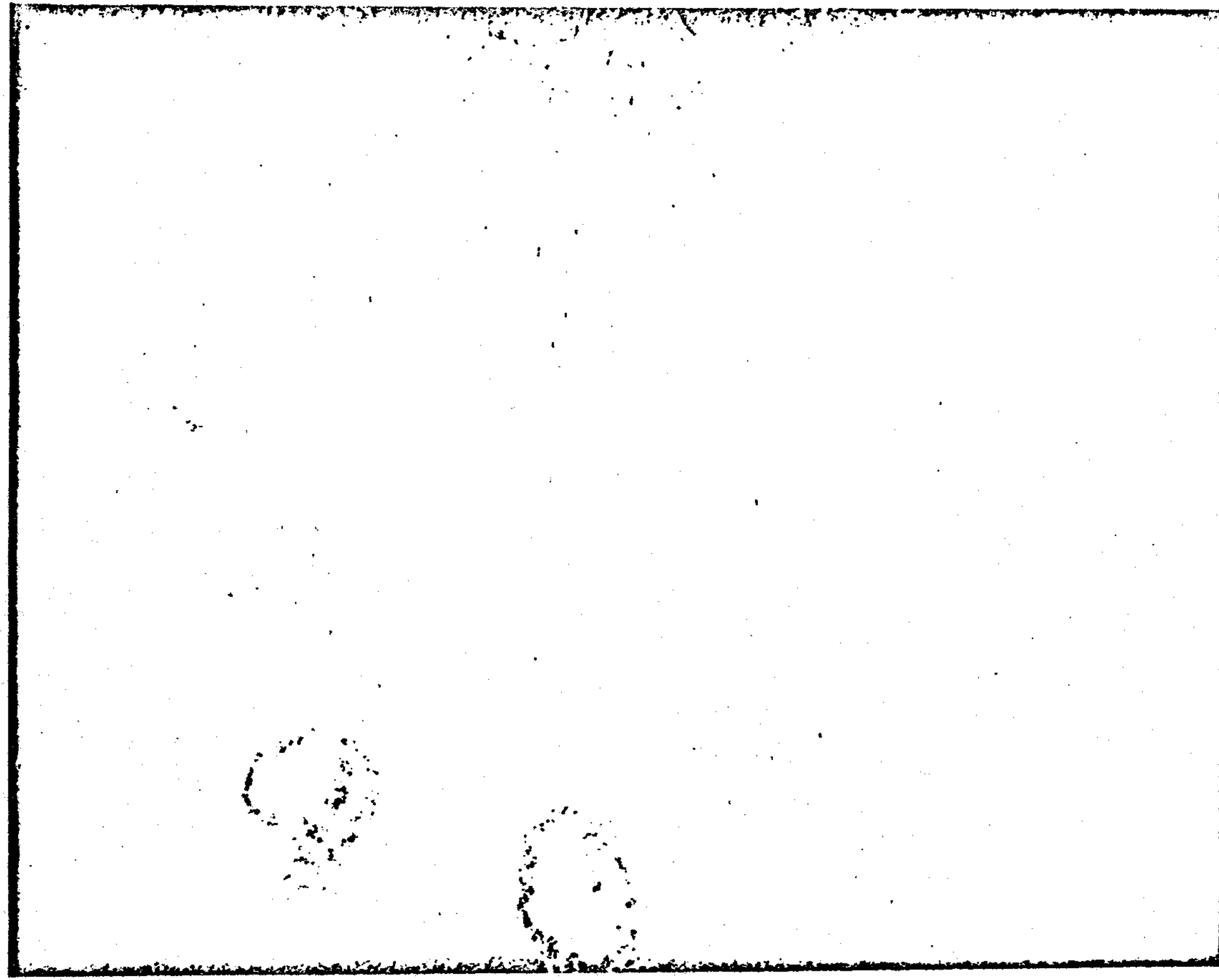


Fig. IV B-33. Area near Rang Rang abandoned airstrip in YT quadrangle showing heavy damage to small forest vegetation in area sprayed four times. Scattered large trees in this area were also killed.

presumed to be the property of RVN the logger is required under RVN law to purchase a cutting permit from the government. However, lack of control of the forests makes it impossible for the government to determine where in fact the cutting is being done. After the logs are harvested and loaded on trucks they are delivered to a government office for scaling and at that point another charge is made based upon log scale volume. This may be referred to as stumpage but it is in fact much more realistic to consider it as an excise tax. Loggers may also have to pay similar taxes to NLF groups and sometimes are assessed additional taxes by provincial authorities. On the other hand, many loggers avoid these payments; the volume of such "illegal logs" has been estimated to be from 50 to 100 percent of the legal harvest, and may be much greater. Under this difficult marketing system the use of a formally prescribed permit fee and excise tax is hardly a basis for assigning a value to forest damage.

A loss estimate based upon market value assumes implicitly that the demand for Vietnamese timber is perfectly elastic; that is, any amount of timber could be harvested and sold without a change in the price. In point of fact the supply-demand situation in SVN under the prevailing security conditions defies formal market analysis. The potential supply of timber in SVN far exceeds current industrial requirements but logs delivered to the mills are commonly in very short supply, due at least in part to lack of personnel for harvest and transportation of the logs, due to mobilization, immobility of workers because of security restrictions, intermittent prohibitions on logging imposed by the government on SVN for military reasons, and other war-related factors.

The use of the official rate of exchange to convert RVN license fees and taxes to U.S. dollars is also a questionable procedure. The value of the piaster on the world market is far less than is reflected in the official exchange rate used in making early projections. Ralston and Tho (1970) state that "the present foreign exchange rate of VN $118 = U.S. $1 is unrealistic and precludes exporting forest products even if production could be increased above domestic requirements."[a]

For all these reasons, the NAS Committee, after having familiarized itself with the situation, decided against any attempts at estimating monetary values of the damage to the forests. It was felt that these were not only of highly questionable value, but might be in fact counter-productive.

Summary and Conclusions

Of the approximately 10,500,000 ha of inland forests in SVN, according to the classification of Rollet (1962a), approximately 1,080,000 ha or somewhat over 10 percent were subjected to herbicide sprays. Of the total sprayed

---

[a] As of March 1973, the official rate had changed to VN $425 = U.S. $1.

area, somewhat under two-thirds was sprayed once, somewhat under one-quarter twice, somewhat under one-tenth three times, and about four percent four or more times. This refers to defoliation and crop destruction operations recorded on the HERBS tape. If the area of all other recorded and estimated herbicide operations (amounting to 17 percent of those defoliation and crop destruction missions) were added to the 1,080,000 ha, the sprayed area would become about 1,265,000 ha or slightly more than 12 percent of the inland forest area. This, however, is an overestimate for the reasons discussed on page IV-71.

The loss of merchantable timber, the damage category which could be approached with the level of precision customary in forest inventory practice, was found to be in the range of 500,000 m^3 to 2,000,000 m^3. The estimated merchantable volume for all inland forests of SVN is about 82,000,000 m^3 (Table IV B-4); for the sprayed part it would thus be about 8,500,000 m^3. The loss estimate thus ranges from somewhat over six percent to 25 percent of the merchantable volume of the sprayed inland forest area, or one-tenth of these percentages for the total inland forest area. Earlier estimates of merchantable timber loss were too large by a factor of 30 to 90.

Our estimate of damage to non-merchantable timber, far less precise than that for merchantable timber, ranges from 5,050,000 m^3 to 11,150,000 m^3.

It should, however, not be assumed from these remarks that the losses of merchantable and non-merchantable timber constitute the entire damage to the inland forests or that all such damage can be expressed in numbers. The damage has been aggravated, in sprayed and in non-sprayed parts of the forest, by other war-related damage. One clear conclusion reached by the Committee is that the greatest damage which the inland forests suffered from war activities, including herbicides, has been incurred by the heavily overused open or thin forests and by the young secondary forests emerging from abandoned swidden. This damage does not appear in the assessment of merchantable timber loss since it represented loss of growing stock below merchantable size and of the early stages of forest regeneration, although it is reflected in the losses of non-merchantable timber. Loss of seed sources may also be a very critical factor in these forests even though the merchantable volume of lost seed trees was quite small. High mortality of seedlings, saplings, and young trees not reflected in merchantable timber loss has in many cases very probably resulted in setting the succession in some sprayed forest areas back for many years. But these losses--of growing stock and seed sources--though very real, could not be evaluated with the precision of the assessment of merchantable timber damage; damage to seed sources could not quantitatively be evaluated at all. Any rehabilitation efforts ought to be based upon careful on-the-ground studies of these two elements of damage.

Damage due to bombing and shelling, whether or not it was associated with herbicide treatment, may well be the most serious and long-lasting of all the war impacts on the inland forest. In the large areas cleared by bombings, not only the merchantable timber, when present, was destroyed but so was all of the growing stock in the opening. Extending far beyond the dimensions of the opening in the forest created by the bomb strike is the damage to living trees caused by shrapnel. These metal fragments in the living trees have already created serious problems for the manufacturers of forest products in SVN in terms of equipment maintenance, loss of yield, reduction in mill productivity, and serious hazards to the operating personnel, and these problems may well persist after the effects of the herbicide operations have disappeared. These problems may indeed reduce both the establishment of new wood-based industries in SVN and the opportunities to sell South Vietnamese logs in the international market, even if the fiscal position of the country improves with respect to the international monetary market so as to render this economically feasible. On a national scale, the economic loss of forest products as a result of herbicide treatment in SVN may not be great. There may be, however, acute localized effects. For example, because of herbicide damage, loggers from a village may have to go a greater distance to harvest trees. This added distance may raise their costs (in terms of money or time) to a point where alternative employment becomes desirable if not a necessity. Considering the substantial displacement of people caused by the war that is not responsive to economic factors, this effect is at present impossible to assess.

Future development of a viable forestry program in SVN, including forest management and development of utilization facilities, will have to include a study of the unusual conditions which have been caused in some forest areas by war damages, separately and in combination. Areas where growing stock and seed sources have been depleted will need to be given special treatment to restore productivity. The longer the delay in taking these measures the more difficult and costly will be the rehabilitation.

Harvesting patterns and utilization practices will have to be devised that will maximize salvage from damaged areas and speed up the development of these areas as productive forests, capable of contributing to the economic progress of the people of SVN, particularly that portion of the population that depends upon the forest and its products for its livelihood.

Since war damage from all causes has undoubtedly resulted in changes in species mix and timber quality, any plans and programs directed at rehabilitation of the damaged areas will require a greater knowledge of the regeneration and growth potential of native species and particularly of the quality and of the present and future utilization potential of these same species.

REFERENCES

Barry, J.P., J. Boulbet, Thung Trung Ngan and H. Weiss, 1960. Introduction a l'etude de la foret dense (Le Massif de la Boucle de la Da Dong). Ann. Fac. Sci. (Univ. Saigon) 239-260.

Boulbet, J., 1960. Description de la Vegetation en pays Ma (Boucle et Plateau de Haut Donnai - Vietnam Sud) Bull. Soc. Etud. Indochin. N.S. 35, No. 3, 3e Trimestre (Saigon), 545-574.

Director of Water & Forest, 1971. Memorandum: Subject - Defoliation with chemicals. (For Secretary General of MLRAFD, dated March 3, 1971, Saigon).

Flamm, B.R., 1968. A partial evaluation of herbicidal effects to natural forest stands principally in Tay Ninh Province. Forestry Advisor, USAID/ADDP, Vietnam.

______, 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.

Flamm, B.R., and H. H. Cravens, 1971. Effects of war damage on the forest resources of South Vietnam. Jour. Forestry 69(11):784-789.

Food & Agriculture Organization Study, 1961. Timber trends and prospects in the Asia-Pacific Region. A joint study by the Secretariats of the Food and Agriculture Organization of the UN and the UN Economic Commission for Asia and the Far East, Chapter 12, p. 91-100.

Gartner, E.J.G., and G.K. Beuschel, 1963. Forest inventory of the Northeastern Region. FAO Report to the Government of Thailand.

Hickey, G., personal communication.

Huberman, M.A., 1959. Bamboo Silviculture. Unasylva 13(1):36-43.

Macabeo, Marcelino E., 1957. Correlation of crown diameter with stump diameter, merchantable length and volume of white Luan (Pentacme contorta [Vid] Meri & Rolfe) in Tagkavouyan Forests, Quezon Province. Phil. Jour. For. 1-2(13):99-117.

McClure, F.A., 1967. The Bamboos. A fresh perspective.
Harvard University Press, Cambridge, Mass.

McKinley, Thomas W. (Forest Resources Advisor), 1957. The forests of free Viet-Nam (A preliminary study for organization, protection, policy and production).
U.S. Operations Mission/Saigon, Vietnam.

Meselson, M.S., A.H. Westing, and J.D. Constable, 1970. Preliminary Report - Herbicide Assessment Commission.
American Association for the Advancement of Science. (Mimeographed)

Murray, James A. and Leland M. Vaughan, 1969. Aerial herbicide applications evaluated for maximum effect and minimum drift.
Department of Army, Fort Detrick, Frederick, Maryland. (AD 873 211).

Pham-Hoang-Ho, personal communication.

Ralston, R.A., and Do Cao Tho, 1970. The forestry sector of the economy of the Republic of Vietnam
(Ministry of Land Reform and Agriculture and Fishery Department, U.S. Agency for International Development and U.S. Department of Agriculture--team effort).
Saigon, Vietnam.

Rollet, Bernard, 1956. Map -- "Vegetation Map of South Vietnam, 1:1,000,000"

______, 1962?a. Note sur la vegetation du Viet-Nam au sud du 17e parallele nord. (Mimeographed)
Transl. by Defense Mapping Agency, Topographic Center, Washington, D.C., November 1972.

______, 1962b. Inventaire Forestier de l'Est Mékong.
Rapport au governement du Cambodge. Programme élargi d'assistance technique, No. 1500 (U.N. Organization for Food and Agriculture, Rome 1962.)

Schmid, M.(?), 1953. Compte rendu de la prospection effectuee dans la region de Blao avec le Professeur Mac Clure de Departement de l'Agriculture a Washington, Specialiste des Bambusees
Unpublished manuscript.

Tschirley, F.H., 1969. Defoliation in Vietnam.
Science 163:779-786.

Westing, A.H., 1970. Poisoning plants for peace.
Friends J., 16:193-194.

Westing, A.H., 1971. Ecological effects of military defoliation on the forests of South Vietnam. BioScience 21(17):893-898.

Williams, Llewelyn, 1965. Vegetation of Southeast Asia - studies of forest types 1963-1965. (Project Report) U.S. Dept. of Agriculture, Washington, D.C. 302 pp.

C. Mangrove Forests

Mangrove forests form an extensive vegetative cover on sediments in salt and brackish water (see Map of Major Vegetation Types in Map Section). They are of some importance in the country's economy because of the number of products obtained from them-firewood, charcoal, timber, tannin, and dyes. They also provide a breeding place for birds, mammals, and fish, and produce organic materials that are absorbed as food by off-shore marine life and stabilize nutrient cycles, as well as provide protection against erosion.

Rollet (1962), using aerial photography taken in 1952-1953, estimated 725,000 acres (290,000 ha) of mangrove forests and 425,000 acres (190,000 ha) of *Melaleuca* woodlands (see Section II E).

Data from the analysis of photography indicate that 262,347 acres (104,939 ha) of mangrove forest have been sprayed by herbicides. This is 36 percent of the total mangrove forest of SVN. Some 12 percent of the *Melaleuca* woodlands (59,260 acres [23,704 ha]) have also been sprayed with herbicides.

In its initial study of the mangrove forests of SVN, members of the Committee made observations from helicopters and light planes. As far as security permitted, observations from the water and on the ground were made in the Rung Sat and in the Ca Mau Peninsula.

Additional studies of mangrove biomass and productivity were carried out in Thailand.

More than 40 species of trees and other plants are commonly found in the mangroves of SVN, but only a few play a major role. *Avicennia alba*, *Rhizophora mucronata* and *Sonneratia alba* are among the first species to invade newly available mud and sand banks. Next, *Ceriops tagal*, *Bruguiera parviflora*, and *Rhizophora apiculata* seedlings also take root, particularly in the *Avicennia* stands, while *Rhizophora mucronata* establishes itself in *Sonneratia* stands. *Rhizophora* and *Bruguiera* species in pure or mixed stands occupy over 75 percent of the area of a well-developed mangrove forest in SVN such as found in the Ca Mau Peninsula.

Sonneratia caseolaris and a palm, *Nypa fruticans*, are characteristic plants found on the banks of the brackish rivers that intersect the mangrove forests. Another palm, *Phoenix paludosa*, and the fern *Acrostichum aureum* become established in the intermediate zone between the inundated mangrove and the non-flooded forests. As the ground is built up and salt water tides are prevented from penetrating, a fresh-water swamp develops in which *Melaleuca leucadendron* usually becomes the dominant species.

(1) <u>Effects of Herbicides on Mangrove Species</u>

From observations in the sprayed mangrove areas of SVN it is clear that applications of Agent Orange and Agent White at a rate of three gallons per acre are lethal to most mangrove species.

Phoenix paludosa appears to suffer substantial damage from one spray including destruction of much of the crown, but the survival rate is high. However, numerous seedlings of *Phoenix* have also been found growing under the dead fronds. *Ceriops* and *Excoecaria* seem like *Phoenix* to be relatively resistant, as evidenced by several large trees growing in an area where *Rhizophora* and *Bruguiera* had been killed by herbicide spray. However, they are usually killed by two or three applications of the herbicide (Fig. IV C-1). Practically all the *Ceriops* and *Excoecaria* trees visible on current air photos are almost certainly survivors of herbicide treatment rather than new seedlings, since they are of large size.

One genus of mangrove trees consistently seen alive in many herbicide-sprayed areas was *Avicennia* (Fig. IV C-3). Surviving trees typically have a cylindrical trunk 8 to 20 in. (20 to 50 cm) in diameter and 6.6 ft (2 m) high with regeneration from the top of the trunk. At some locations in the Rung Sat, it was observed that the surviving *Avicennia* trees had grown from stem buds but these shoots had been trimmed for firewood. The recovered trees are no more than 10 to 13 ft (3 to 4 m) high. Several of these trees have been observed on photographs made before and after spraying, and on the ground. A number of these surviving trees, as well as *Phoenix* and *Ceriops* in herbicide-treated parts of the Rung Sat occur in a pattern suggesting streaks of incomplete overlap between parallel spray patterns. These observations suggest that *Avicennia* may survive a reduced dosage or even the usual spraying of 3 gal./acre of Agent Orange or Agent White. Surviving *Avicennia* trees were also commonly found along the banks of streams which are the sites usualy occupied by this species.

Detailed observations of mangroves in the Rung Sat and Ca Mau areas will be presented since these were the main areas of Committee work on this topic.

Fig. IV C-1. Remains of a dense stand of *Ceriops tagal* in the Rung Sat Special Zone. Dead trees were cut for firewood and charcoal. Photo taken by Dr. C. P. Weatherspoon, December 15, 1972.

Fig. IV C-2. Numerous *Ceriops tagal* seedlings in the Rung Sat Special Zone above edge of high tide as indicated by moist dark soil in background. Stumps are mainly *Ceriops tagal*. *Avicennia officinalis*, and *Phoenix paludosa* in background. Photo taken by Dr. C. P. Weatherspoon, December 15, 1972.

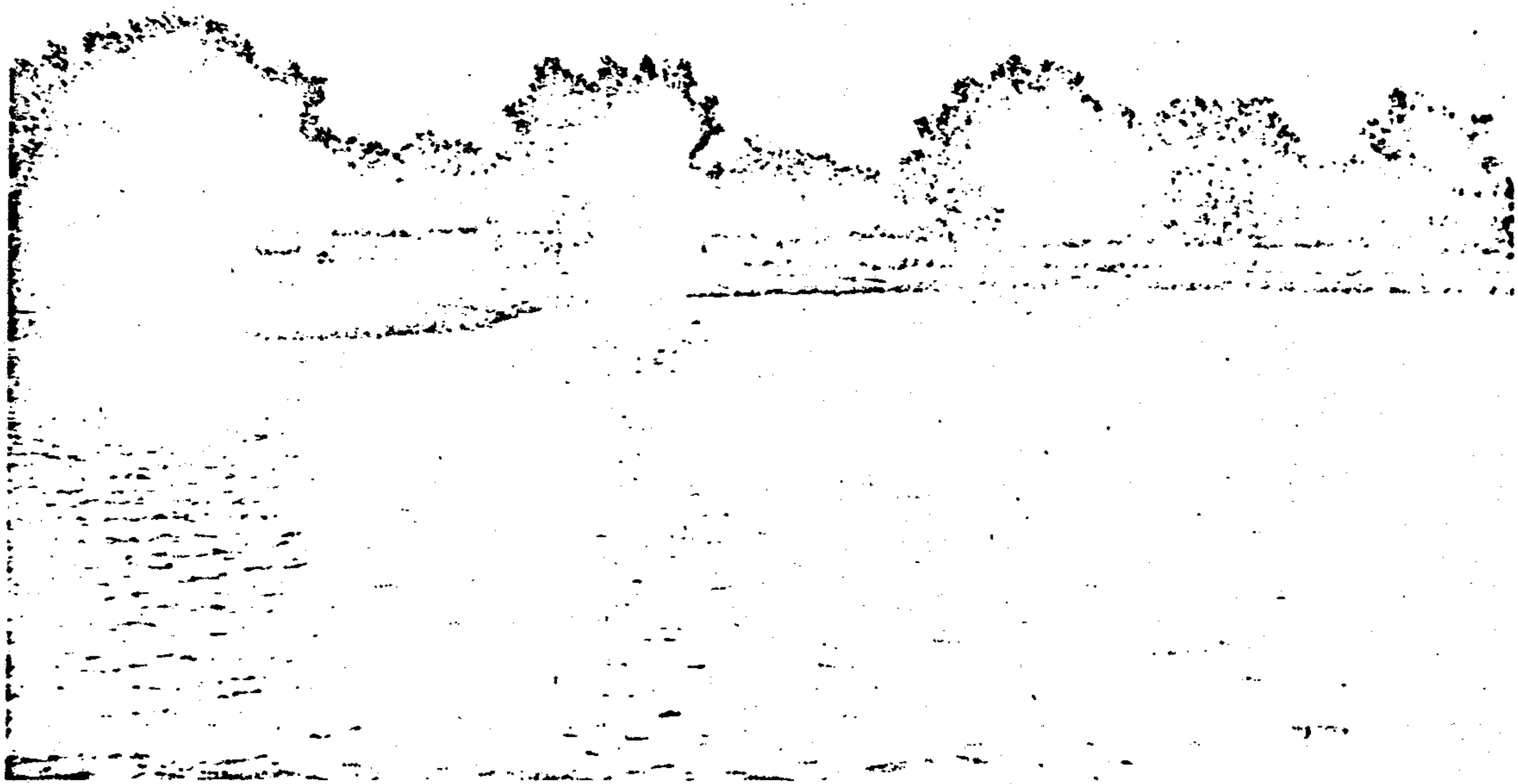


Fig. IV C-3. Surviving Avicennia officinalis along stream banks covered with mats of Paspalum vaginatum in the Rung Sat. Photo taken by Dr. C. P. Weatherspoon, December 15, 1972.

(2) The Rung Sat

The Rung Sat includes approximately 405 mi^2 (1053 km^2) of tidal swamp interspersed with many channels. Analysis of aerial photography by the Committee indicates that before the spraying of herbicides, approximately 51 percent of the area of the Rung Sat was covered by mangrove trees, 23 percent of the area covered by water, i.e., streams, 8 percent cultivated, 6 percent abandoned cultivation, 5 percent brush, 5 percent bare ground, and 2 percent cultural features. The land is so low lying that the highest tides during June-July and December-January cover the entire area. The Delta is formed of recent alluvia from deposits of the Saigon, Dong Nai, and Thi Vai Rivers and the sea. The soil is predominantly acidic clay, with large quantities of sulfides, which become oxidized to sulfates when exposed to air. A strip of sandy soils is found from Dong Hoa to Can Gio along the coast and extending some distance inland. These are often used for intensive agriculture.

The mangrove vegetation of the Rung Sat prior to the increased American military presence of the 1960's was a secondary formation, having been cut over and disturbed for many years. Rice farmers and fishermen living around the perimeter of the mangroves gathered construction wood and firewood. The only primary formations of mangroves probably were on the northern half of Phu Loi Island; these were not cut by the villagers as they were considered sacred and served as shelter from the monsoon winds (Vu Van Cuong, 1964).

Approximately 57 percent of the Rung Sat area was sprayed with herbicide between 1965 and 1970 (see Table IV C-1 and Figs. IV C-6 and C-7). In flying over the Rung Sat one gets the impression of large areas of denuded soil or mud flats with scattered trees or clumps of trees (Fig. IV C-4). In order to quantify the changes in the Rung Sat a South East to North West transect across the area was analyzed comparing 1958 World Wide Survey black and white photography (1:45,000 scale) with 1972 color photography (1:5000 scale). The transect is 18 miles (28.8 km) in length and 3750 ft (1125 m) in width (Fig. IV C-5). Eighty-five percent of the transect was sprayed from 1965 to 1970. The remaining unsprayed area, which is mainly under cultivation, is located in the northwest end of the transect.

By 1972, as can be seen in Table IV C-2, the area occupied by living mangrove trees declined from 55 percent to only 15 percent of the sprayed area of the transect, whereas bare soil with no vegetation had increased from 2.3 to 34.6 percent. The percentage of the vegetation types in the unsprayed portion of the transect has changed only little over the time period. In addition, *Phoenix paludosa* now occupies approximately 4 percent of the sprayed area of the transect and is not found in the unsprayed area of this transect.

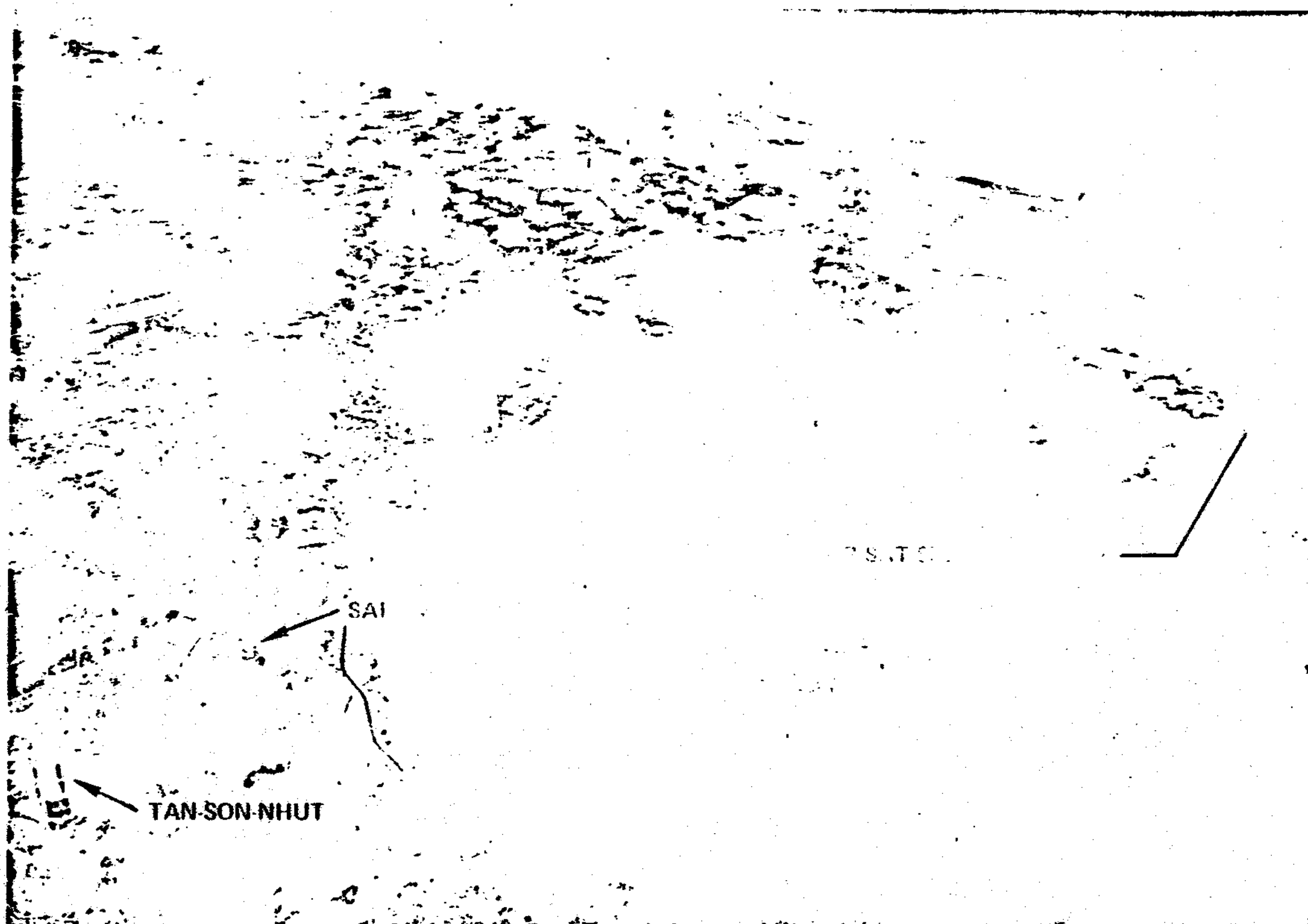


Fig. IV C-4. Oblique photograph of the Rung Sat Special Zone and Saigon area taken January 29, 1972.

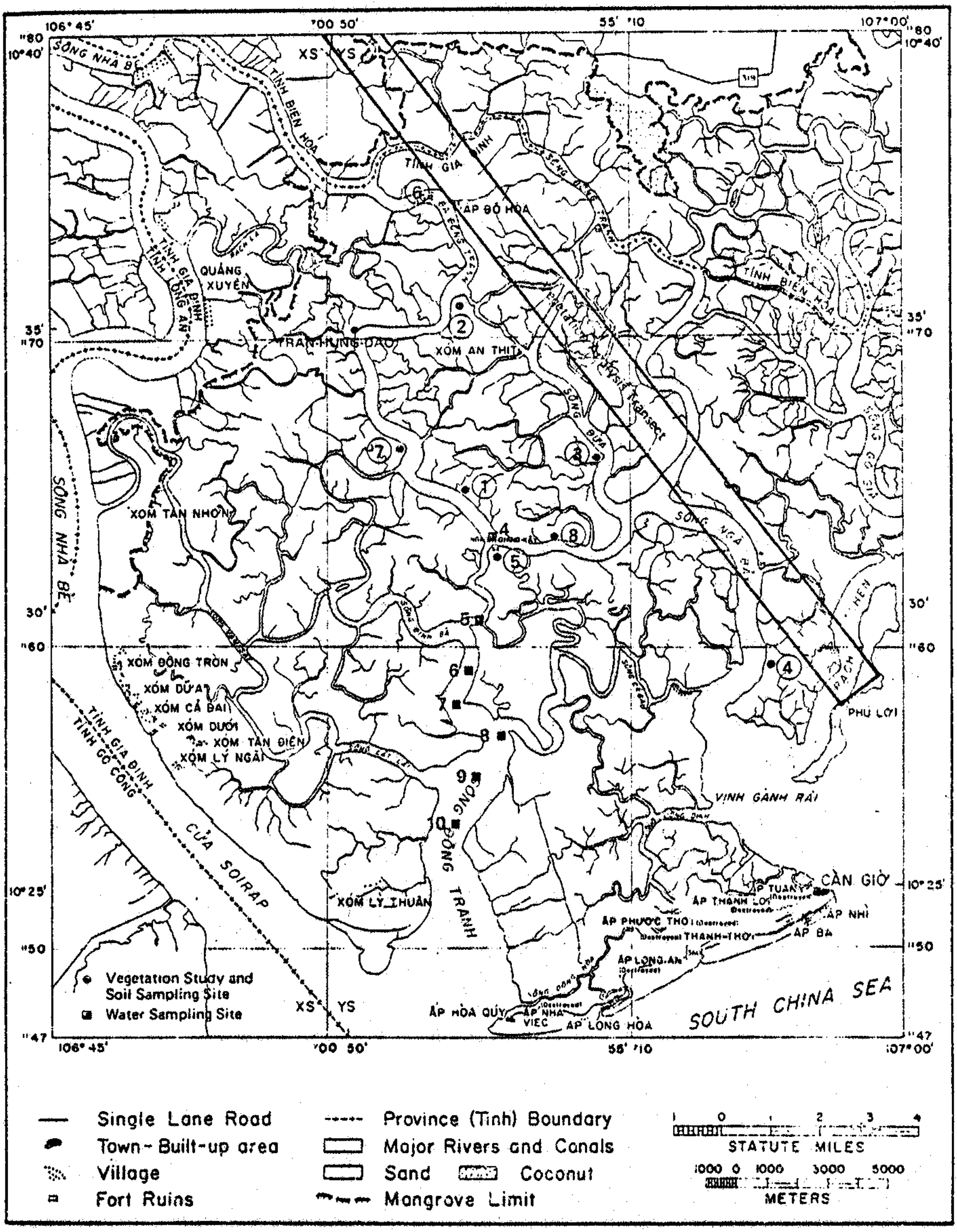


Fig. IV C-5. Soil, Water and Vegetation Study Sites in the Rung Sat Special Zone.

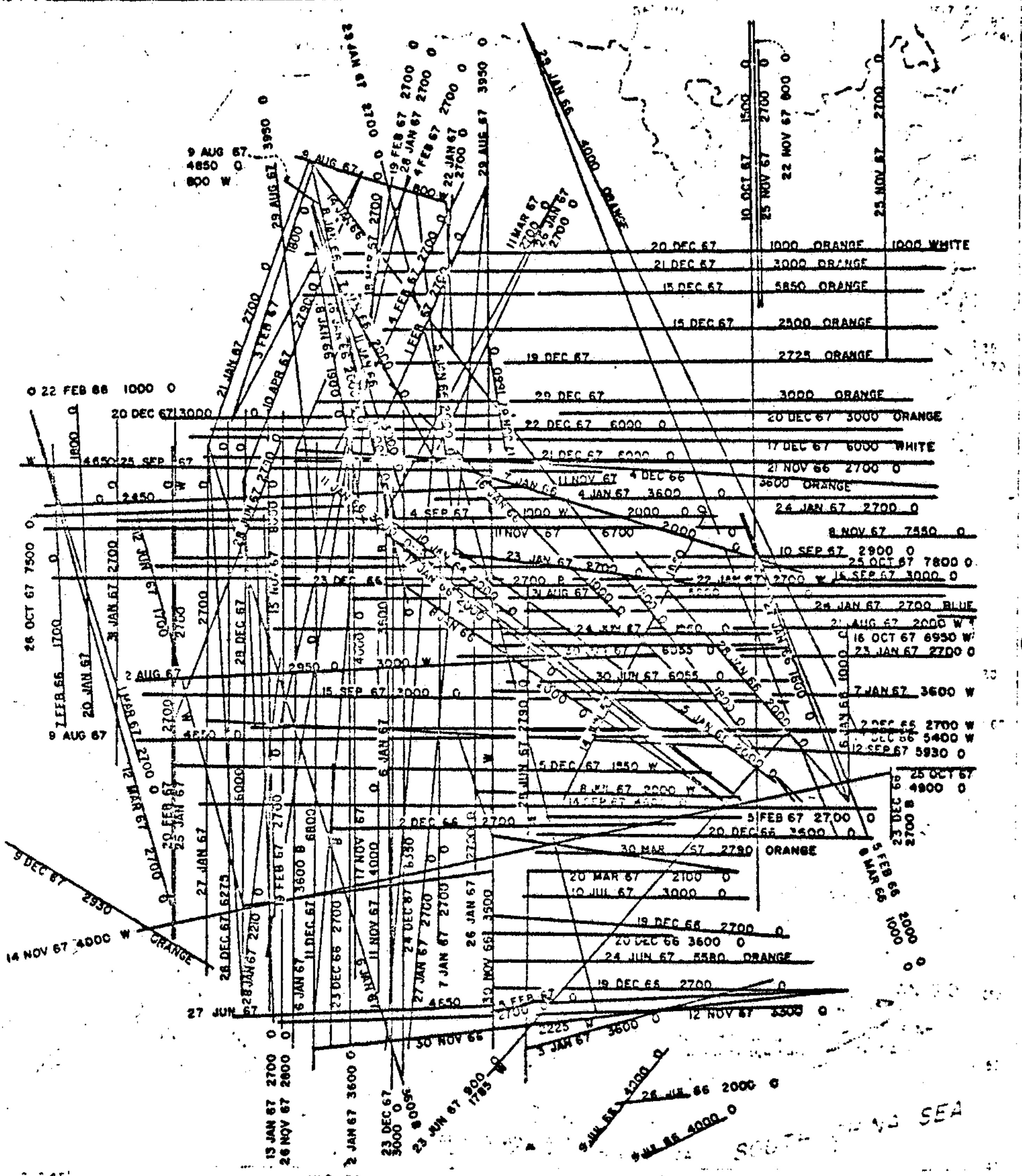


Fig. IV C-6. Herbicide Spray Missions 1966-1967 in the Rung Sat Special Zone. Data from HERBS tape includes date of mission, number of gallons, and type of Agent.

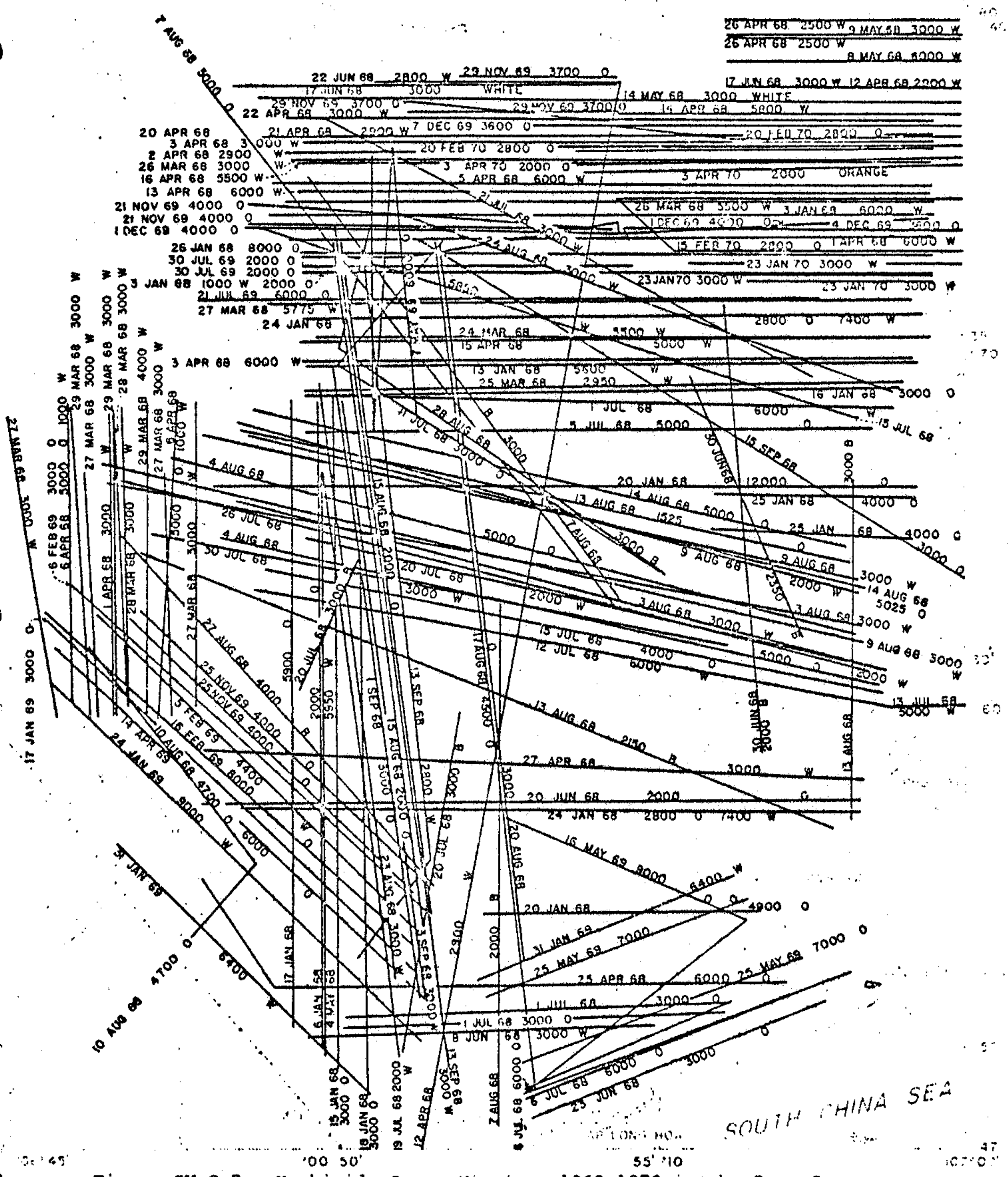


Fig. IV C-7. Herbicide Spray Missions 1968-1970 in the Rung Sat Special Zone. Data from HERBS tape includes date of mission, number of gallons, and type of Agent.

Table IV C-1

Classification of the Rung Sat with Percent Sprayed and Unsprayed

Unit	Percentage of Area in 1958	Percentage Sprayed	Percentage Unsprayed
Trees	51.2	33.5	17.7
Formerly Cultivated	6.3	2.6	3.7
Brush and Herbaceous Vegetation	4.9	3.9	1.0
Cultivated	7.9	0.8	7.1
No Vegetation (Total)	5.4	3.3	2.1
Bare Soil		0.5	0.9
Mud Flats		1.0	0.1
Tidal Flats		1.8	1.1
Cultural Features	1.6	0.1	1.5
Water (Total)	22.7	13.1	9.6
Small Streams < 40 m		4.6	3.8
Medium Streams 40-200 m		2.4	1.3
Large Streams > 200 m		6.1	4.5
Totals	100	57.3	42.7

Note. The table shows the percentages of the various surface and vegetation types ("units") that were sprayed in the course of the herbicide operations. The pre-spray composition is taken from the 1958 World Wide Survey Photography, the percentage sprayed and unsprayed from 1972 photography. Between 1958 and 1972, some non-herbicide-related changes in the units may have occurred, e.g. abandonment of additional cultivated land or conversely extension of such land. The analysis of the transect (see Fig. IV C-5) indicates however that such changes were quite small (see Table IV C-2).

Table IV C-2

Comparison of Sprayed and Unsprayed Portions of the Rung Sat Transect in 1958 and 1972
(From 1958 WWS photography, 1972 Committee photography)

Unit	Percentage of Unit in Area - 1958 Sprayed	Percentage of Unit in Area - 1958 Unsprayed	Percentage of Unit in Area - 1972 Sprayed	Percentage of Unit in Area - 1972 Unsprayed
Trees	55.0	5.6	15.3	6.7
Formerly Cultivated	1.9	5.5	2.1	3.0
Brush and Herbaceous Vegetation	8.2	0.5	11.6	1.8
Cultivated	--	1.1	--	2.0
Debris	--	--	0.3	--
No Vegetation (Total)	2.3	0.1	34.6	0.4
Bare Soil	0.4	0.1	20.4	0.2
Mud Flats	0.8	--	0.4	--
Tidal Flats	1.1	--	13.4	0.2
Craters	--	--	0.4	--
Cultural Features	0.1	0.1	0.2	0.3
Water (Total)	18.0	1.6	20.7	1.0
Small Streams < 40 m	4.0	1.4	4.2	0.5
Medium Streams 40-200 m	2.3	0.2	2.2	0.5
Large Streams > 200 m	11.7	--	14.3	--
Totals	85.5	14.5	84.8	15.2

Note. The table compares the sprayed and unsprayed portions of the transect, as seen in the 1972 photography, with the equivalent portions of the intact mangrove (1958 photography). The small differences in the percentage coverage reflect mainly changes in the vegetation which occurred in the 14 years between the two photo coverages. The apparent difference in total sprayed and unsprayed areas (85.5 versus 84.8 percent and 14.5 versus 15.2 percent) is due to variations in the exact scale of the photos and similar factors.

(3) Ca Mau Peninsula

The southern tip of SVN, the Ca Mau Peninsula, was almost entirely covered with dense mangrove forests up to 1968. Several large rivers, the Bay Hap, Cua Lon, Dam Doi and Bo De, drain the interior sections of the Peninsula and bring salt water from the sea by a dense network of drainage streams (Figs. IV C-8 and C-12).

Up to 1928 there was indiscriminate cutting of the mangrove for charcoal from the logs and tannin from the bark. In 1928, French foresters established forest reserves and started to manage the mangroves systematically. In 1934 a major development program was established with laws regulating cutting, with canals dug for extraction of wood, and with replanting of denuded areas, all with the aim of managing the mangrove for the charcoal and tannin industries. During the next 15 years, 38,000 hectares were replanted, mainly with Rhizophora apiculata (Moquillon, 1949).

Thus, prior to the arrival of the American Forces in the Ca Mau Peninsula, the mangrove forests were mainly even-aged stands of Rhizophora apiculata with some Bruguiera parviflora. These trees often reached 100 ft (30 m) in height and 3.3 ft (1 m) in diameter. In areas in which there was a buildup of sediments near the shore, Avicennia alba and Excoecaria agallocha were the first colonizers followed by Rhizophora apiculata and Bruguiera parviflora seedlings, which rapidly attained dominance. Recorded measurements show that Rhizophora has an annual growth of 3.3 ft (1 m) in height and 0.28 inches (7 mm) in diameter and it has been calculated that it would take up to 30 years before Avicennia was replaced by Rhizophora on newly deposited silt (Moquillon, 1949). In addition to Rhizophora, Ceriops tagal could also be grown as pure stands. Inland pure stands of Nypa palm line the small streams where the salinity is lower than in the large streams leading to the sea.

Bare or grassy swamps can be found in the interior where Rhizophora trees disappear because of stagnation of brackish water diluted by rain, accumulation of decaying organic matter, a diminished salinity, and a rise in temperature.

Herbicides were first used in the Ca Mau Peninsula in 1962, when targets along the Ong Doc River and the canals between the Cua Lon and Bay Hap Rivers as well as the banks of these two rivers were sprayed. The major spray missions in this region were carried out in 1967 (Fig. IV C-9) and the damaged swaths are still clearly visible (Figs. IV C-10 and IV C-11). Current photography (1973) of the Ca Mau Peninsula shows that approximately 52 percent of the area is bare of mangrove trees.

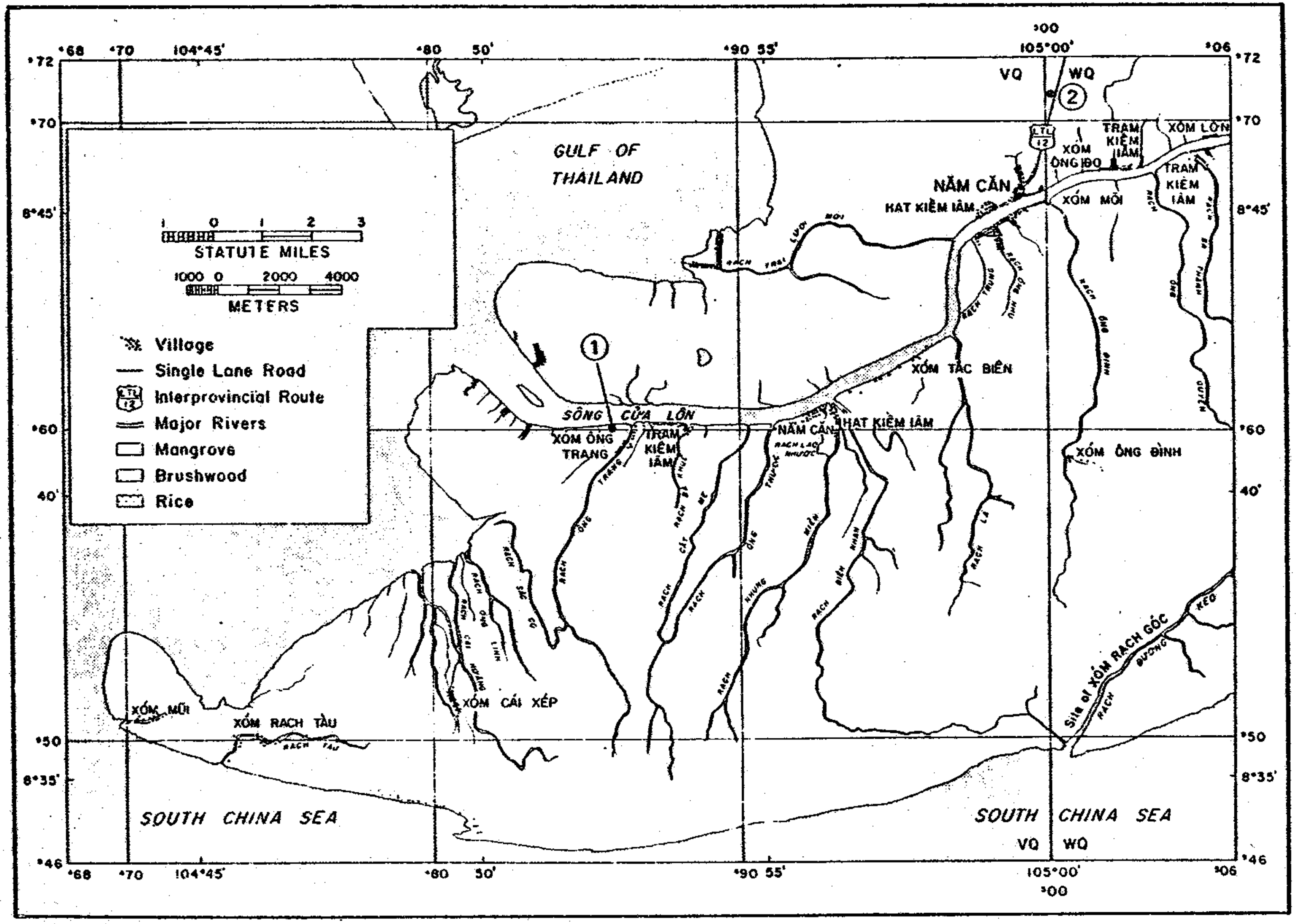


Fig. IV C-8. Tip of Ca Mau Peninsula, An Xuyen Province showing the two Committee study sites.

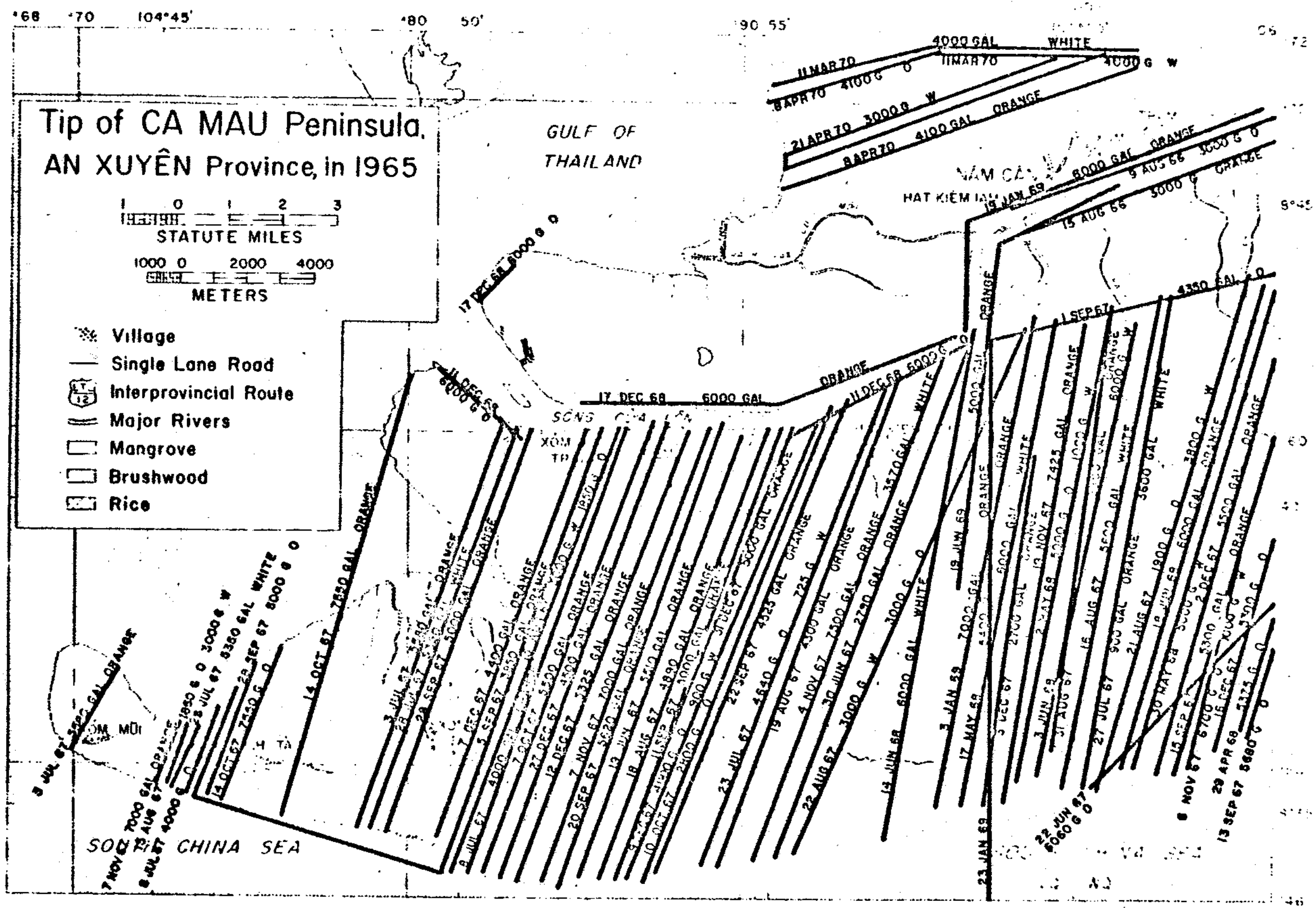


Fig. IV C-9. Herbicide Spray Missions 1966-1970 in the tip of the Ca Mau Peninsula, An Xuyen Province. Data from HERBS tape includes date of mission, number of gallons, and type of Agent.

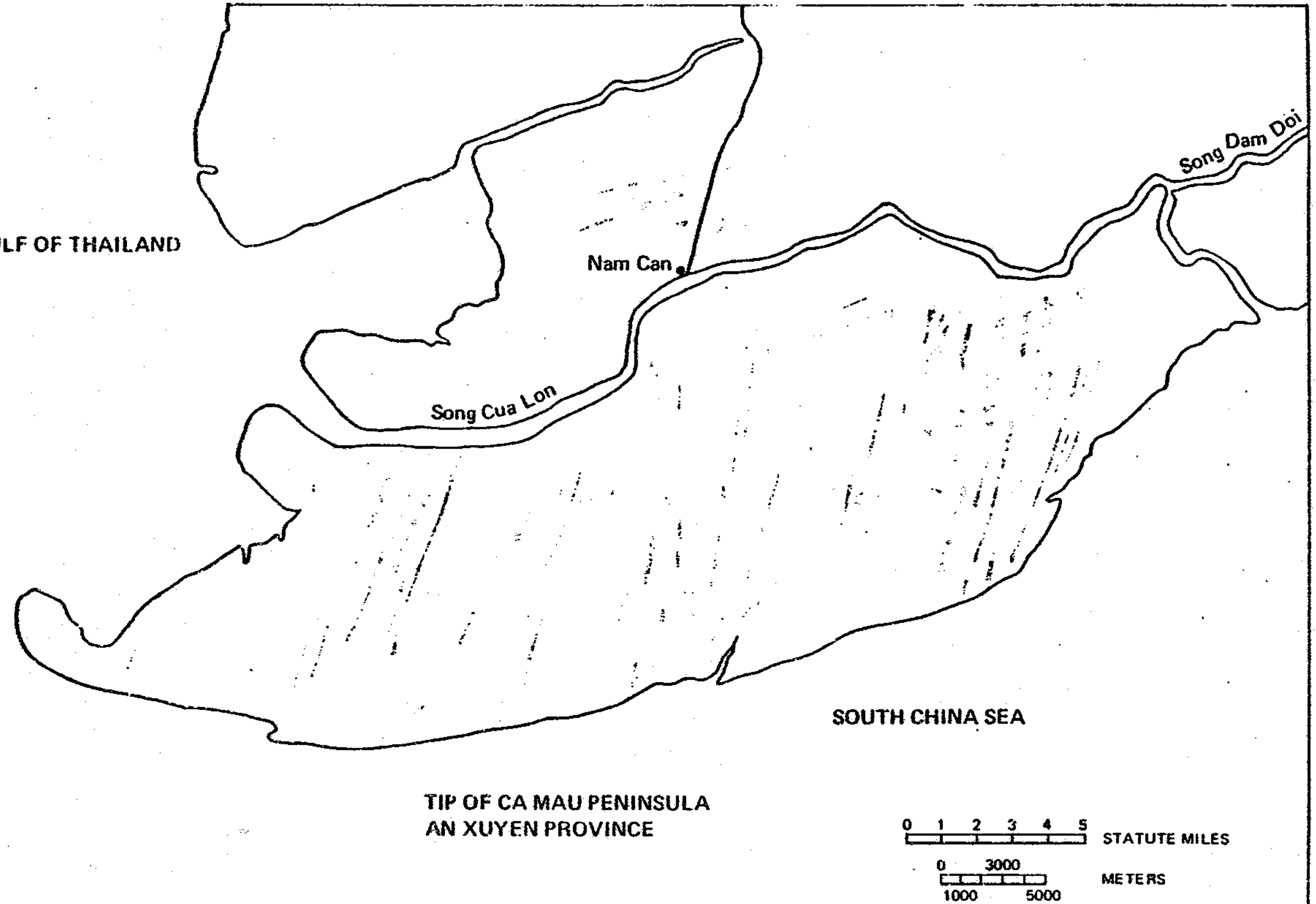


Fig. IV C-10. State of the Mangroves on the tip of the Ca Mau Peninsula, An Xuyen Province in 1972, showing bare areas from herbicide spray missions. Map drawn from 1972 aerial photography.

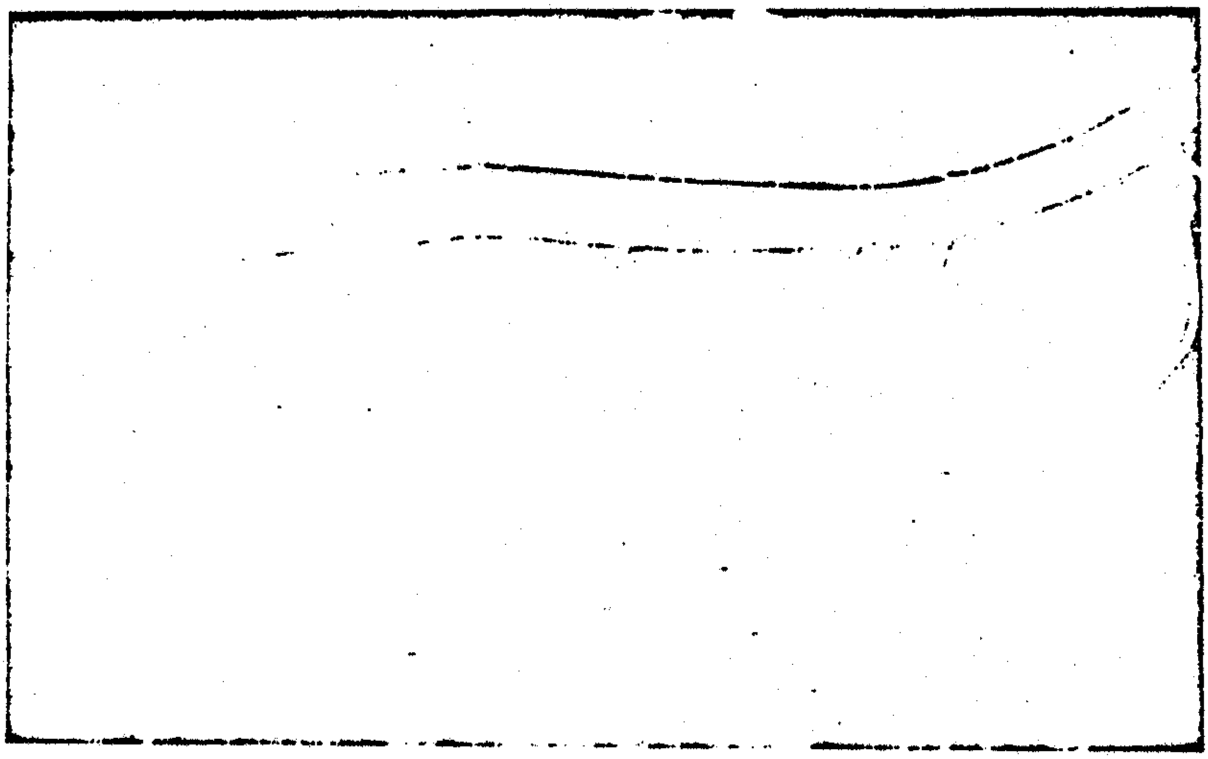


Fig. IV C-11. The Cua Lon River below Nam Can showing effects of herbicide spray missions. DOD film (U.S. Air Force) taken in May 1969.

Fig. IV C-12. The Cua Lon River below Nam Can showing mangrove forests before herbicide spray missions. Aerial photo taken January 1958 by World Wide Survey.

(4) Factors in Recolonization

Revegetation comes about by two processes: the recovery of surviving damaged plants, and establishment of new plants from seedlings. Literature data and our observations suggest that success of natural regeneration in the mangrove forest depends upon depth of water, frequency of flooding, soil moisture, salinity of water and mud, nutrient availability and pH status of soil, previous occupants of the area, presence of debris on the mud surface, presence of adequate seeds and seedlings for restocking, protection of the seedlings by existing vegetation, and damage to seedlings by crabs.

Limited data gathered on depth of water, salinity and pH of the water and mud, and temperature of the mud surface suggest that these environmental conditions are in the normal range for growth of mangrove plants and should not limit regeneration according to information from various countries (Chapman, 1966; Davis, 1940; Macnae, 1966; and Watson, 1928).

The situation may be different in relatively elevated areas, which are flooded only at highest tides. Here, presumably because of high evaporation and insufficient tidal movement, higher salinity levels have been found (up to about 50 ppm, as compared to 24-32 ppm in small nearby creeks) and these and possibly also higher soil temperatures may be unfavorable for the establishment of seedlings.

Soil nutrients were found to be in a range that should not limit plant growth; in fact, the nutrient content of the soil in completely bare regions in the Rung Sat was higher than in a non-defoliated mangrove on the Ca Mau Peninsula (see Table V B), suggesting that the nutrient status of the soil was not the reason for the failure of extensive revegetation.

Herbicide determinations in Rung Sat soil and plantings of seedlings on experimental plots at different times after herbicide application to the soil, carried out by the Committee (see Section V A), showed that while there are still some herbicide residues (2,4,5-T and picloram) in the Rung Sat, they are far below levels that would inhibit seedling establishment. In fact, seedlings could be successfully planted as early as three weeks after a herbicide treatment equivalent to one herbicide mission. The experiments indicated also that the establishment of mangrove seedlings may be adversely affected if an area is cleared of vegetation. Seedling survival on such an area, cleared of vegetation by hand (with no subsequent herbicide application) was much poorer than on small plots cleared within an undefoliated mangrove. This finding can however not be generalized because survival of hand-planted seedlings in an area of the Rung Sat which had been completely denuded by herbicides was quite good (see p. IV-110).

In the Ca Mau area large quantities of stems, roots, and other trash were present on the mud surface in the bare areas and relatively few seedlings were encountered. Trash may act as a filter, preventing fruits and seedlings of mangrove plants from reaching bare inland areas, and may also cause damage to young established plants by movement of the trash through tidal wave action (Watson, 1928; Walker, 1938). On the flat banks of the larger rivers to 100 ft (30 m) inland abundant regeneration has occurred in some places.

The availability of seeds and seedlings for recolonization of the sprayed areas appears to be the major critical factor in revegetation of defoliated areas. A large number of seedlings of Bruguiera and Rhizophora were observed in floating trash on the Cua Lon River in the Ca Mau Peninsula, and many plants of Avicennia, Bruguiera, Rhizophora, and Excoecaria were observed in fruit in non-sprayed areas. These observations suggest that adequate seeds and seedlings are available for regeneration in the Ca Mau area. In contrast, relatively few seeds or seedlings were observed floating in the canals of the Rung Sat. The major remaining seed source is the northeastern area, which was not sprayed but has been heavily cut over by woodcutters. Distribution over the Rung Sat from this source would be exceedingly slow. Crabs, which were observed to be numerous, both in Ca Mau and the Rung Sat, may destroy mangrove seedlings colonizing the sprayed areas. Crab damage to mangrove regeneration in the Ca Mau is mentioned by Moquillon (1949). The Committee observed such damage to seedlings by crabs in plantings carried out near Vung-Tau, although it did not seem to be a major factor preventing establishment.

In the sprayed areas in the Ca Mau, the river and canal banks inland to 220 yards (200 m) are being naturally repopulated with the economically desirable mangrove genera, Rhizophora and Bruguiera, which should flower in four years (Fig. IV C-13). Farther inland from the canal and river banks, the process of revegetation is much slower, probably due to the trash on the ground preventing seedling distribution (Fig. IV C-14). In October 1971 this trash was in advanced stages of decay and may be gone in two or three years from then, at which time seedling dispersal over the area by water might be possible.

The Rung Sat is a different case. There are no major seed sources nearby. If allowed to develop, the living Avicennia and Ceriops--which were apparently more resistant to herbicides than other mangrove tree species--will produce seeds that will help recolonize the area (Fig. IV C-2). Given normal development, these plants should flower and fruit in a few years and would help supply seeds and seedlings. However, it appears that as soon as young trees grow to pole size they are cut and removed for firewood. The number of generations required to restock successfully the entire Rung Sat is not known. Since seed sources of the economically more valuable Rhizophora and Bruguiera are very scarce, reestablishment of a typical, mature, economically useful mangrove forest may take decades.

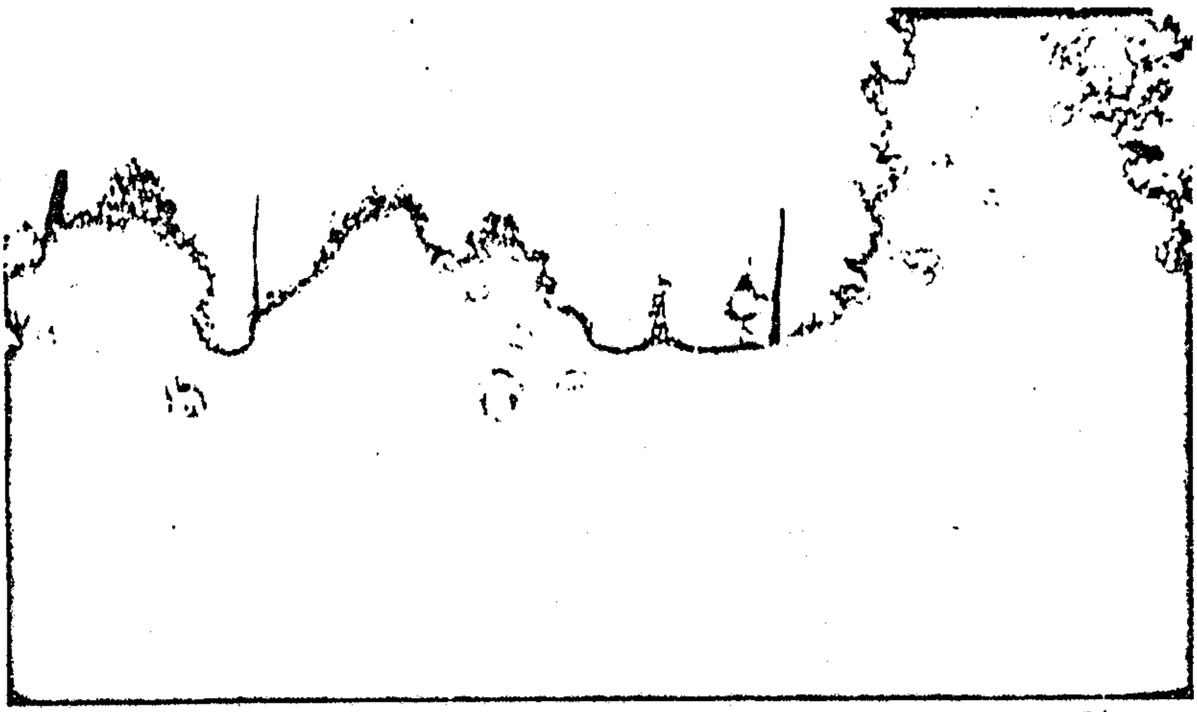


Fig. IV C-13. Defoliated section of canal bank of the Cua Lon River, Ca Mau Peninsula, with Rhizophora seedlings and surviving Avicennia officinalis. Area sprayed in 1967. Photograph taken October 1971.

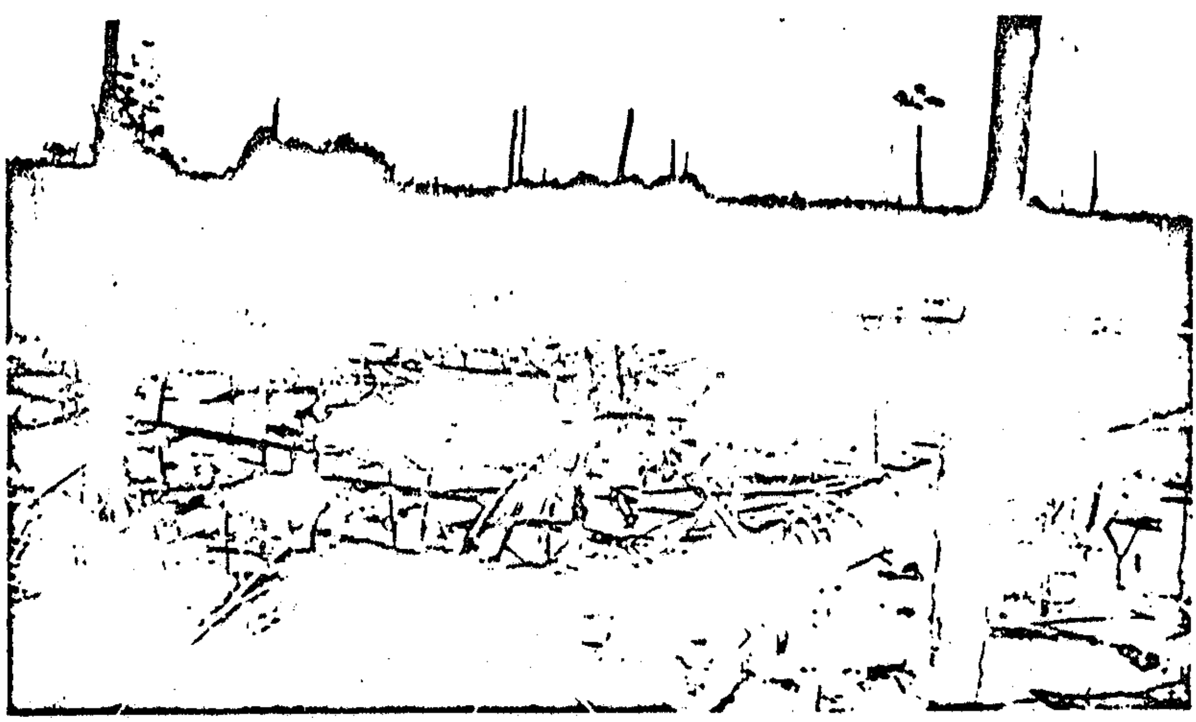


Fig. IV C-14. Defoliated section of the mangrove forests of the Ca Mau Peninsula. Area sprayed in 1967. Photograph taken October 1971.

Because an adequate natural seed source for recolonization of the Rung Sat is not available, various methods of replanting mangrove seedlings were tested during March and August 1972 on Thanh An Island in the Rung Sat. The island had been sprayed at least once and along the west coast several times. Seedlings of *Rhizophora apiculata* and *Ceriops tagal* gathered from trees in the unsprayed areas of the Rung Sat were used in these tests. The planting tests were evaluated in December 1972. The results indicate that *Rhizophora* and *Ceriops* seedlings planted by hand in defoliated areas will survive and grow. Between 50 and 66 percent of the seedlings planted in the higher and drier areas had survived about half a year after planting; between 80 and 85 percent had survived in more moist areas.

To test a quicker planting method, seedlings of both *Rhizophora* and *Ceriops* were dropped from a helicopter. Some seedlings were packaged with sand to which a slow releasing fertilizer had been added, and were provided with "tails" (streamers of paper) assuring that they would land in an upright position. These seedlings survived and exhibited very rapid growth. Other seedlings, packaged without fertilizer or with no packaging, did not fare as well. These experiments were not extensive enough to make generalizations, and should be extended if reforestation of large parts of the Rung Sat mangrove area is considered. Together with the planting studies in the Vung Tau mangrove they suggest, however, that replanting of mangrove is possible although, if to be done on a large scale, quite a formidable task.

(5) Ecological Role of *Acrostichum Aureum* in the Mangrove Forest

A large fern, *Acrostichum aureum* is commonly found throughout the mangrove forests of the world tropics, including SVN. Usually in unsprayed or uncut mangrove forest, it occurs widely but with a small number of individuals per unit area. Concern has been expressed that this fern, which is considered a pest species, will occupy extensive areas where the mangrove trees have been clear-cut or destroyed (Figs. IV C-15 and C-16). An evaluation of aerial photos of the transect area (see above) taken before and after the herbicide operations and checked by on-the-ground observations, indicates that the area occupied by *Acrostichum* in the Rung Sat may have increased in this time (that is, 1958-1972) from about five to about six percent of the total area. It is however not certain whether or to what extent this is related to defoliation, since come changes in the surface "Units" (Table IV C-2) have occurred in the unsprayed part of the transect. Two-thirds of the area covered by the fern are found in the sprayed areas which were either formerly cultivated or covered with brush or herbaceous vegetation.

It is estimated that under the ecological conditions now prevalent in the Rung Sat the fern will probably not overgrow most areas where the former mangrove forest has been largely destroyed by herbicides. In some areas, the extent of which is not known, ecological conditions may well exist favoring successful germination of the fern spores, as observed at only one locality among those visited in the Rung Sat. Under such evidently uncommon circumstances, some colonization by the fern will no doubt occur; but if a year of close observation of the same sites is a valid measure of fern colonization, it will be a slow process on the bare areas. Finally, where seedlings and saplings of the woody mangrove species develop in a stand of fern, the increasing shade formed as the forest canopy is gradually restored will be expected ultimately to eliminate the fern.

Fig. IV C-15. Dense vegetation of Acrostichum aureum in the Rung Sat. Photograph taken by Dr. Howard J. Teas on November 8, 1972.

Fig. IV C-16. Acrostichum aureum in the Rung Sat. Photograph taken December 1972.

(6) <u>Estuarian Studies in the Mangrove Forest</u>

Studies on the effect of defoliation of the mangroves on the estuarian ecosystem were carried out in the Rung Sat Special Zone. The physical nature of the water, the plankton, and fish in the Rung Sat area and at a control site not defoliated near Vung Tau were studied in October-November 1972 and January 1973 (Fig. IV C-17). The molluscan fauna in these same areas was also examined.

A comparison of Rung Sat and Vung Tau water suggests that water temperature and pH were similar in the two areas, while dissolved oxygen was lower and turbidity was higher in the Rung Sat. As expected, turbidity was lower in the dry season, in both the Rung Sat and Vung Tau areas. Salinity in the Rung Sat also was lower, as would be expected, since there is an influx of fresh water from the Saigon and Dong Nai Rivers into this area. Salinity was also higher in the dry season in both the Rung Sat and Vung Tau areas. Plant and animal plankton samples collected suggest that both areas are rich in variety of planktonic organisms and in numbers of individuals, but the variety and number in the Rung Sat is lower than at Vung Tau. These organisms also tend to be more numerous in the wet seascr in both the areas. Fish eggs were more frequent in the Rung Sat, as were fish larvae, but the distribution of catches was more even in Vung Tau, and Vung Tau also had a greater variety of fish larvae (15 families in the wet season, 17 in the dry for Vung Tau versus 9 in the wet season and 11 in the dry season in the Rung Sat collections). In contrast, larger fish were more abundant in Vung Tau, but the variety of fish was about the same in both seasons. Benthic collections were difficult to evaluate and although more individuals were collected at Vung Tau the data are too limited for a conclusion of area difference (Table IV C-3).

The observations suggest that the defoliation of the mangrove forest in the Rung Sat produced for several years a large increase of decomposed organic matter which may have increased some components of estuarine life and fish production, lowered oxygen and through increased turbidity diminished some phytoplankton production. By 1973 with the dead mangrove material now removed by wood cutters, decomposed or washed out to sea, this organic source has decreased but it is uncertain whether phytoplankton production will increase enough to compensate for the lower food source until mangroves or other vegetation recovers.

The total marine (including estuarine) fish catch in SVN by motorized fishing boats has somewhat increased in the years of herbicide operations (1962-1969) although the increase was small and irregular (Table IV C-4). In contrast, the mean catch per boat has declined, except that a slight upswing is indicated in 1969. This decline may reflect economic, social, technological and other changes (e.g., increased use of motorized craft; in SVN, also decreased safety and hence reduced operation times) as much as, and possibly more than, changes in the water and biota. However, the mean catch per motorized fishing boat for Taiwanese trawlers in the South China Sea and Thai trawlers in the Gulf of Thailand increased over the same time span (Table IV C-4). Loftas (1970) reported that "the size of fish caught (by Vietnamese fishermen) has decreased until the more popular species have had to be protected by setting size limits."

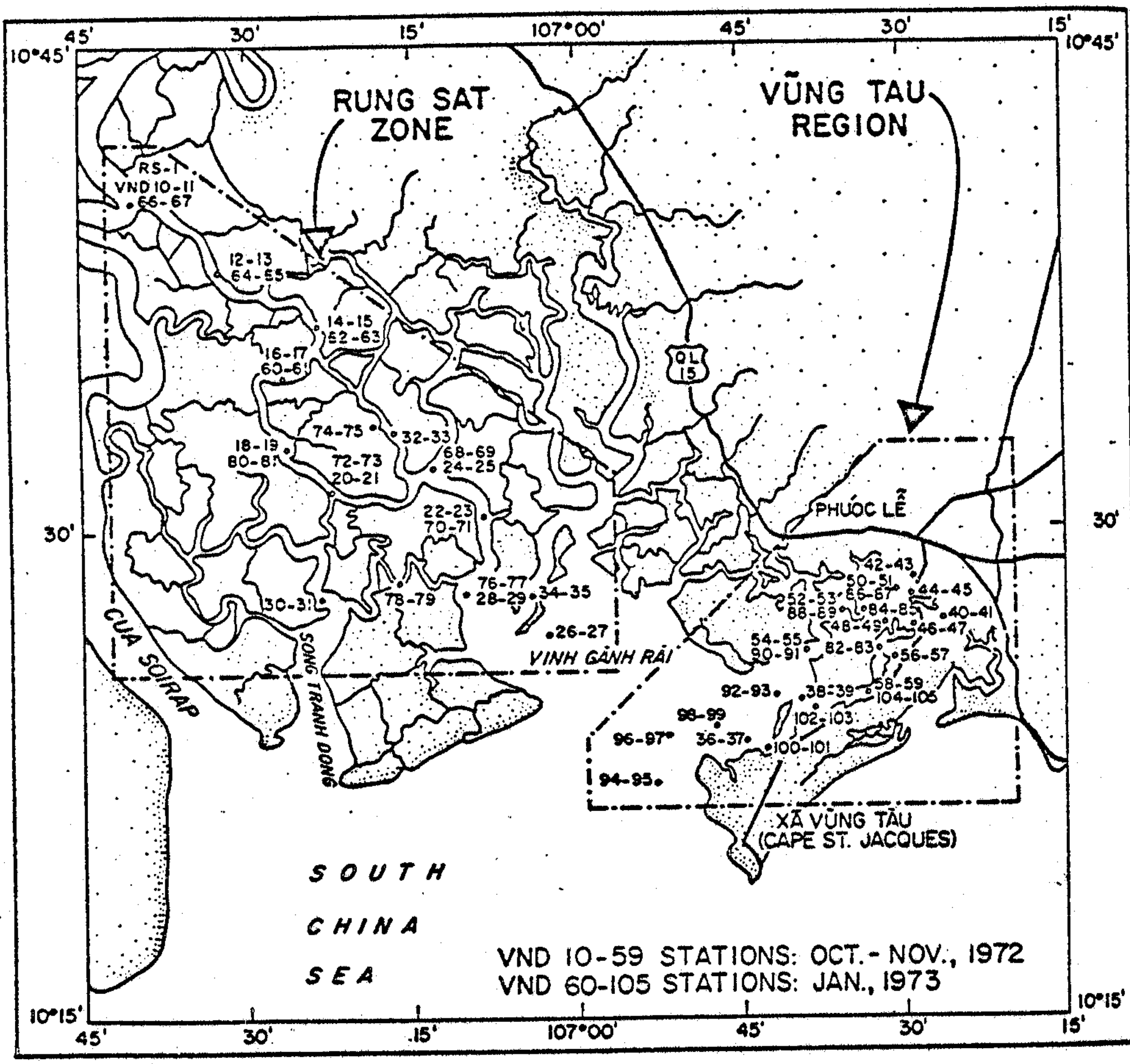


Fig. IV C-17. Location of collecting stations in the Rung Sat Special Zone and the Vung-Tau Region, SVN, 1972 and 1973.

Table IV C-3

Summary of hydrographic and biological data collected in mangrove region of South Vietnam, 1972-73. Rung Sat is defoliated; Vung Tau is non-defoliated (control region). Wet-season collections were made in October and November, 1972. Dry-season collections were made in January, 1973. Numbers are means of collections at stations shown in Fig. IV C-12.

	Rung Sat wet	Rung Sat dry	Vung Tau wet	Vung Tau dry
Average values for each area				
Temperature, °C	28.8	27.4	29.5	26.8
Oxygen, ppm	4.1	4.4	5.6	6.4
Oxygen saturation, %	67	67	90	98
Salinity, o/oo	11.5	17.0	27.8	30.7
pH	7.5	7.4	8.0	7.9
Turbidity, JTU[a]	62	55	8	4
Number of organisms				
Copepods[b]	127×10^3	117×10^3	273×10^3	114×10^3
Diatoms[b]	106×10^4	456×10^2	511×10^4	229×10^3
Fish eggs[c]	422	2,242	277	1,146
Fish larvae[c]	1,864	10,469	268	274
No. fish families[d]	9	11	15	17
Sponges	1	0	8	6
Corals, etc.	5	6	44	29
Worms	15	249+	101	66
Clams, etc.	35	11	104+	28
Crustaceans	783	2,741	1,207	1,712
No. crustacean families	13	18	19	19
Sea stars, etc.	4	2	81	28
Fish	104	215	240	250
No. fish families	17	10	17	16

---

[a] Jackson Turbidity Units

[b] Organisms caught in a 15 minute tow of a 0.1 mm mesh, 0.5 m mouth diameter plankton net.

[c] Organisms caught in a 15 minute tow of a 0.5 mm mesh, 0.5 m mouth diameter plankton net.

[d] Remaining organisms in list were caught in a 15 minute tow of a stretched mesh, otter trawl trynet.

Table IV C-4

Catch (metric tons), number of trawlers, and catch per motorized fishing boat in the South China Sea and the Gulf of Thailand, 1952-1970.
Data from Brouillard (1970), Shindo (1973) and Viet Nam Statistical Yearbook (1971).

	Vietnamese vessels, coastal South Viet Nam			Japanese trawlers, South China Sea			Taiwanese trawlers, South China Sea			Thai trawlers, Gulf of Thailand		
	catch, tons x 1000	trawlers	effort	catch, tons	no. trawlers	effort	catch, tons	no. baby trawlers	effort[a]	catch, tons x 1000	no. trawlers	effort
1952	-[b]	-	-	3,079	14	219	-	-	-	-	-	-
1953	-	-	-	11,730	30	391	-	-	-	-	-	-
1954	-	-	-	12,045	31	388	2,214	468	4.3	-	-	-
1955	-	-	-	8,171	23	355	2,623	558	7.8	-	-	-
1956	-	-	-	8,389	30	279	3,657	685	7.8	-	-	-
1957	-	-	-	10,283	29	354	4,802	867	6.9	-	-	-
1958	-	-	-	16,461	74	222	4,837	862	7.6	-	-	-
1959	-	-	-	8,155	23	354	5,518	918	8.8	-	-	-
1960	-	-	-	5,647	14	403	6,040	962	9.1	-	-	-
1961	-	-	-	1,007	10	101	7,122	1,044	9.1	123	201	612
1962	-	-	-	384	4	96	6,984	964	12.7	151	976	155
1963	299	9.220	32	166	2	83	8,529	1,195	14.2	277	2,026	136
1964	314	9,710	32	0	0	0	11,905	1,386	15.5	372	2,360	158
1965	289	12,240	24	0	0	0	13,666	1,501	20.8	393	2,396	164
1966	287	16,770	17	0	0	0	16,857	1,756	28.2	449	2,695	166
1967	319	23,195	14	0	0	0	23,310	1,979	32.0	583	3,077	189
1968	321	29,968	11	0	0	0	30,061	2,374	29.1	784	3,182	247
1969	355	39,001	9	0	0	0	32,886	2,278	33.9	908	3,185	285
1970	442	42,603	10	0	0	0	34,751	2,129	40.8	-	3,114	-

[a] Annual total per gross ton
b Data not available.

The molluscan fauna on the land near the water locations were also studied. While the collections were very limited in time, number, and area, the data indicate a rich molluscan fauna in the region of interest. The molluscs presently characteristic of the Rung Sat are those able to tolerate the heat on the mud flats, and which can obtain food under the open conditions. Where grass and trees occur, the molluscan fauna is richer and it may be expected that the fauna will recover fully if the forest is reestablished.

(7) <u>An Estimate of Requirements for Restoration of Defoliated Mangroves</u>

The preceding discussions have considered various individual components of the mangrove separately. In conclusion, it will be useful to consider the mangrove and its environment as a single system.

As was shown in Table IV C-1, before herbicide spraying about 51 percent of one of the major mangrove areas of SVN, the Rung Sat, was forest and 23 percent was water; the rest was bare soil, brush, and cultivated land. Fish, shrimp and other food chain organisms in the waters were receiving organic matter from three sources: (1) three inflowing rivers, (2) the mangrove itself, and (3) photosynthesis of phytoplankton. Organic matter influx from these sources is typical of all mangroves. A vigorous tide exchanged most of the estuarine waters with the South China Sea every few days. Oxygen levels in the water were apparently between 5 and 6 ppm, which is slightly below saturation but is expected where there is high oxygen consumption by organic matter coming in from rivers and swamp. Acidity was in the range of pH 6-7 in low salinity zones, gradually going up to the usual value of pH = 8.2 in the open sea. The waters were slightly turbid, as is characteristic of a river delta region.

After spraying, and as examined in 1972, defoliation and other changes such as increased river traffic, dredging, and more use of motorized fishing vessels had affected the mangrove and aquatic ecosystem in several ways. Increased turbidity of water due to organic detritus from decomposing mangrove and to greater siltation evidently contributed to decreased phytoplankton and zooplankton, thereby lowering oxygen levels to between 3 and 4 ppm. There was no significant change in pH during this period. These effects may also have influenced the fish and other higher organisms in the system, although we do not know what part of the decline in fish catch per unit effort was due to loss of mangrove habitat, to overfishing, increased water turbidity, or other factors.

Because some of the foods for aquatic life in the estuary are being sustained by decomposition of the dead mangroves in the sprayed areas a continuing decline in this fraction of the estuary's nutritional status may be anticipated. If revegetation of this area is delayed, there will be a delay in restoring the mangrove component to the fishery food chains. However, if the fraction of organic matter that comes from the rivers does not change, the phytoplankton may increase again as turbidity decreases, and its contribution to aquatic productivity may increase.

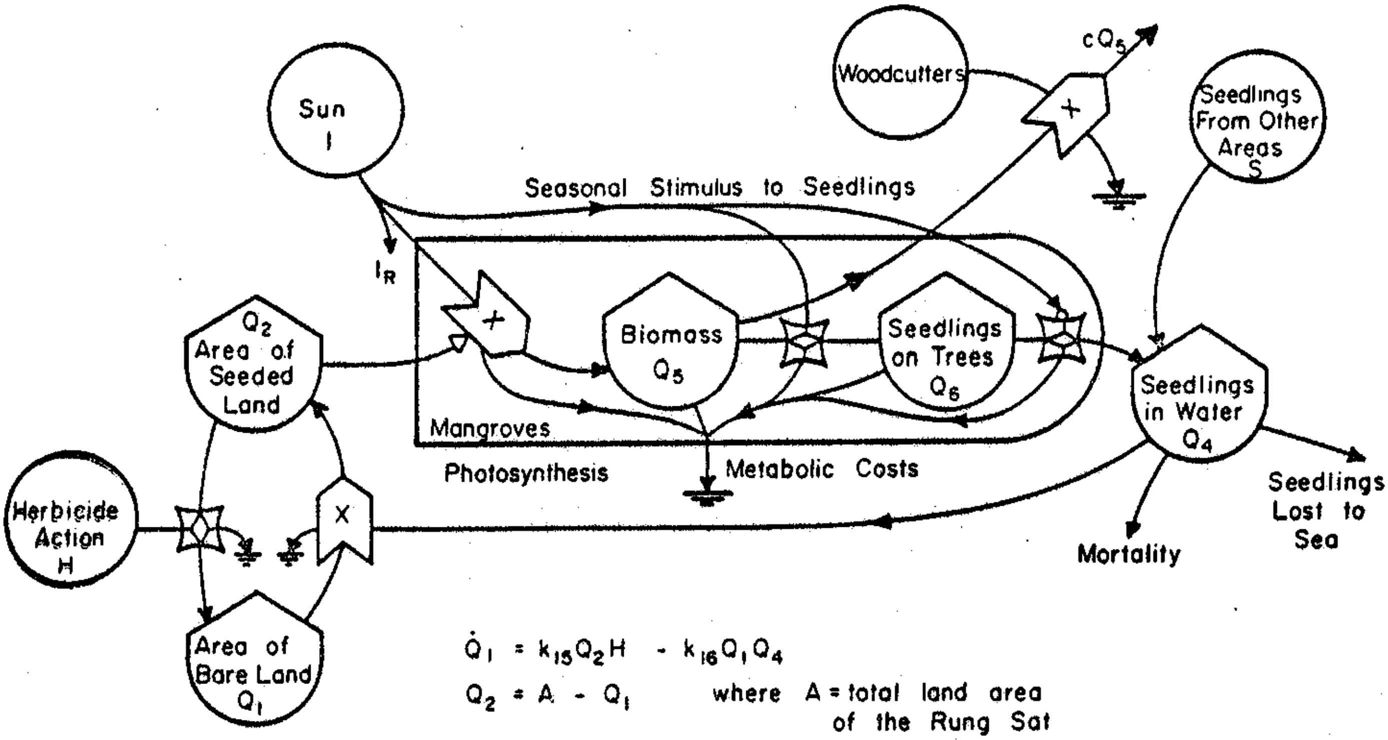
These considerations suggest that not only the mangrove forest, which of itself has some economic value, but also the estuarine systems may depend on recolonization of the sprayed mangrove forest. One major impediment of recovery in the Rung Sat is the availability of seeds and seedlings. Some mangroves, e.g., <u>Rhizophora</u>, reproduce by means of large seedlings which do not drop from the parent tree until they are eight inches (20 cm) long or more; others, e.g., <u>Avicennia</u>, by nut-like fruits. In all types of mangrove trees the seedlings or nuts float, and are dispersed by tidal water. In managed Rhizophora mangrove forests the recommended practice for artificial regeneration is to start two seedlings per square meter (about 11 square feet). In the Rung Sat, far too few trees have remained to supply that quantity of seedlings or fruits. The undefoliated mangrove areas to the East, in Phuoc Tuy province, are not large enough to provide sufficient seedling and fruit numbers either and are moreover so located in relation to the Rung Sat that the fruits or seedlings which are released into water do not effectively reach the bare areas. Cutting for firewood keeps the trees moreover scrubby, with large specimens producing high seed yields relatively few. There is also a large mortality of fruits and seedlings between the time of their release and establishment of a sapling tree.

Following from these considerations, a calculation was made of the number of seedlings required to reestablish an acre (0.4 ha) of mangrove forest under various management plans over a series of years. This was done with the aid of a model of mangrove reforestation simulated on a computer. The model and the principal equations entering into it are shown in Fig. IV C-18. The derivation of the model is given in the working papers which form part of the background material for this Report. As should be noted the model shows that the main factors controlling the reestablishment of mangrove in bare areas are supply and survival of seedlings. As new trees grow up they begin to produce seedlings and those from trees along channels are contributed to the general pool in tidal waters. If woodcutting is as extensive as it now is, with few large seedling trees remaining, then seedling shortage may continue for many years. The figures actually used in the calculations, and their sources, are given in the upper part of Table IV C-5. Where no information from the Rung Sat, or SVN in general, was available, data from mangroves in other countries were used. The calculations were made for Rhizophora, because certain data (seedling production, planting density for reforestation) are available mainly for this genus and because this is the economically most valued genus of mangrove trees in SVN. The results are given in Table IV C-5, lower part, and Fig. IV C-19.

The results show that in the central Rung Sat, the number of seedlings becoming established is only a tiny fraction of that required for rapid reforestation (Table IV C-5). To achieve full stocking--that is, coverage of the entire defoliated area with mangrove trees or seedlings--in 50 years, 15 surviving seedlings per acre are estimated to be needed each year from seed producing trees or from areas outside the defoliated acre. Given the various assumptions and approximations in Table IV C-5, calculation of the rate of natural revegetation under existing conditions without introduction of seedlings from the outside suggests that revegetation would require as much as 120 years (Fig. IV C-19). Artificial revegetation methods such as aerial or hand planting could reduce the time required to reach full stocking. Thus, 100 years could probably be saved by broadcast of 1000 seedlings per acre per year, and about 70 years by using one-fifth of this number (Table IV C-5, Fig. IV C-19). If seedlings were hand planted, fewer would be required.

The Committee is aware and has already pointed out that artificial revegetation of large mangrove forest areas is a formidable task. The whole Rung Sat is about 1053 km^2 or about 260,000 acres in size. Fifty-seven percent or about 150,000 acres have been defoliated. Thus, 150,000,000 seedlings or the seedling yield of over 5000 to 10,000 acres (over 2000 to 4000 ha) of mangrove forest would be needed annually. Such numbers may only be obtainable from other parts of Southeast Asia where there are active management programs, adding to the money and manpower requirements. The above calculations are however not made in order to imply that a revegetation program of this scale should be started as soon as possible, but to provide a measure of the time and effort needed for restoration of destroyed mangrove. It should also be borne in mind that the above calculations involve a number of assumptions the degree of accuracy of which is uncertain. Thus, we have assumed 65 seedlings to be naturally established by 1972 per acre in the Rung Sat, but on our visits to different parts of the area we found a great variation in this number, including areas of at least one acre with not a single mangrove tree seedling. If such areas are extensive, natural revegetation will clearly require even more time than in our estimate. With artificial revegetation methods, however, the effect on the estimates would be small because the naturally established seedlings represent in any case but a small fraction of the introduced ones. On the other hand, we have assumed a survival of only 10 percent (Table IV C-5, item "Number colonizing bare areas"). In our own planting experiments in the cleared area near Vung Tau (see Section V A-3) survival was indeed of this magnitude, but in hand plantings in a completely defoliated area in the central part of the Rung Sat it ranged between 50 and 85 percent (Section IV C-4). If survival should be closer to the latter figures, recovery with artificial planting would take less time than estimated above, or alternatively less seedlings would have to be introduced to accomplish recovery in a given time. The use of the Rung Sat as the example probably also overstates the entire case insofar as this is the mangrove region with the largest continuous areas with little if any vegetation left. In other mangrove regions like the Ca Mau Peninsula, individual defoliated areas are relatively smaller and intermingled with intact ones (see Figs. III B-8, IV C-10, and IV C-11), and this should improve the prospects for natural revegetation and reduce the effort or the time which would be needed for artificial replanting.

One question that arises in any reforestation problem is the availability of plant nutrients in the soil. Herbicide operations in the mangrove were often followed by woodcutters who removed the remaining above-ground parts of the dead mangrove trees, and at least in some areas even the stumps are being dug out. Thus, nutrients present in the wood are removed from the system. However, soil analyses in intact, defoliated and hand-cleared mangrove (Section V B) suggest that changes following removal of vegetation have been at the most small. Phosphorus seems to be supplied in considerable amounts by the riverflow each year. Thus, lack of soil nutrients does not appear to be nearly as serious a factor as seedling supply.



$$\dot{Q}_1 = k_{15}Q_2H - k_{16}Q_1Q_4$$

$$Q_2 = A - Q_1 \qquad \text{where } A = \text{total land area of the Rung Sat}$$

$$I_R = I - k_2Q_2I_R$$

$$\dot{Q}_4 = k_{11}Q_6 - k_{12}Q_4 - k_{13}Q_1Q_4 + S$$

$$\dot{Q}_5 = k_3Q_2I_R - k_6Q_5 - k_7Q_5 - cQ_5$$

$$\dot{Q}_6 = k_8Q_5 - k_{10}Q_6 - k_9Q_6$$

Fig. IV C-18. Model and equations used for estimating seedling and time requirements for revegetation of defoliated mangrove (Rhizophora) as shown in Fig. IV C-19.

Symbols:

- ◯ = energy inputs into the system from the outside
- ⬡ = energy storages within the system
- ⟨x⟩ = multiplier control actions for one factor onto another
- ⊠ = on-off switching actions
- ⏚ = energy leaving the system after its work has been done

In the diagram, energy is shown going into mangrove biomass in proportion to the area of seeded land and the intensity of sunlight. Mangrove biomass losses occur through several pathways including woodcutting, growth of seedlings on trees, respiration, and mortality. The storage of seedlings is balanced by an inflow of mangrove biomass and losses due to metabolism and seasonal release into the water. The seedlings floating in the water are the balance of those falling from the trees, those from other areas, those washed out to the sea, mortality, and those colonizing bare land to form seeded land. Seeded land is shown to become bare land in proportion to herbicide action. These relationships are written also in equation form.

Explanation for the Items in the Equation for the Model in Fig. IV C-18

A. Forcing Functions (outside influences)

I = Solar energy flux hitting the mangroves of the Rung Sat

H = Herbicide application to mangroves of the Rung Sat by the U.S. military

S = External seedling source that may be needed to regenerate the mangroves

B. State Variables (levels considered important in the model)

Q_1 = Mangrove land that has been converted to bare land by herbicide spraying

Q_2 = Land occupied by mangroves in the Rung Sat

Q_4 = Seedlings that are present in the water at any chosen period in time for the entire Rung Sat

Q_5 = Total biomass of the Rung Sat mangroves

Q_6 = Seedlings that are present on the mangroves of the Rung Sat

C. Process Variables (rate coefficients)

k_2 = Light utilization ($1.43 \times 10^{-3} km^{-2}$)

k_3 = Photosynthetic conversion ($7.54 \times 10^{-6} kcal^{-1}$)

k_6 = Respiration ($5.85 \times 10^{-1} yr^{-1}$)

k_7 = Growth of seedlings on trees ($1.311 \times 10^{-1} yr^{-1}$)

k_8 = Production of seedlings (5.17 seedlings $kg^{-1} yr^{-1}$)

k_9 = Seedlings fall into water ($2.02 \times 10^{-1} yr^{-1}$)

k_{10} = Seedlings remain beneath parent tree ($1.0\ yr^{-1}$)

k_{11} = Seedling availability to colonize ($2.15 \times 10^{-3} yr^{-1}$)

k_{12} = Loss of seedlings in water ($1.05\ yr^{-1}$)

k_{13} = Seedlings colonize new areas ($4.2 \times 10^{-2} yr^{-1}$)

k_{15} = Conversion of seeded land to bare land (4.8×10^{-7} liters$^{-1} yr^{-1}$)

k_{16} = Conversion of bare land to seeded land (2.56×10^{-8} seedlings$^{-1} yr^{-1}$)

c = Wood cutting ($3.06 \times 10^{-2} yr^{-1}$)

Table IV C-5

Seedlings Numbers for Reforestation of *Rhizophora*

Data on Seedlings	Seedlings per Acre
Recommended planting for reforestation[a]	8,000
Spontaneously established in central Rung Sat by 1972[b]	65
Number produced on an acre of large, well-nourished trees[c]	28,000
Number surviving within a scrubby, cut-over forest in Vietnam[d]	14,400
Number reaching open water from seed source areas[e]	450
Number colonizing bare areas by calculation[f]	12
Computer Simulations (see Fig. IV C-18)	
Number of seedlings starts from outside that must survive each year to achieve full canopy in 50 years[g]	15
Number of seedlings starts from outside that must survive each year to achieve full canopy in 15 years	75

[a] Moquillon (1944), Noakes (1955).

[b] Counts of seedling in 50 ground photographs taken in 1972.

[c] Counts from Puerto Rico, Florida and SVN.

[d] Counts at Vung Tau, March 1972.

[e] Seedlings produced on the edge of tidal canals where ratio of canal margin to swamp area is about 2 m/100 m^2 and 83 seedlings overhanging per meter of canal per year; seedling area 100 m^2 (Rookery Bay, Florida).

[f] One-quarter reaching bare areas and 10 percent of these surviving.

[g] Assumes that seedlings are intorduced from outside each year, and that the stated number of seedlings survives at least to the end of the first year, thereafter to be subject to normal mortality. Regeneration will be to an extent determined by land uses.

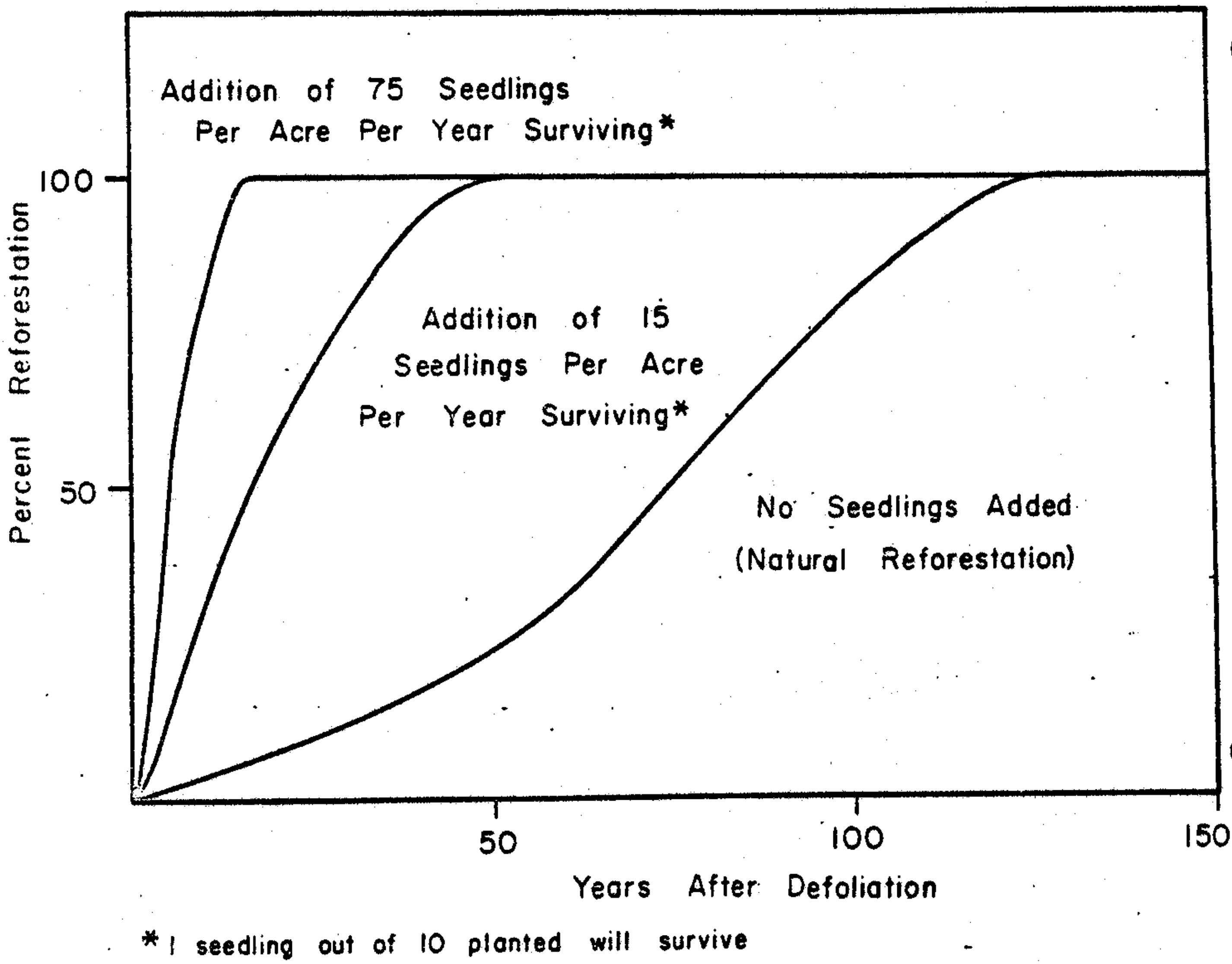


Fig. IV C-19. Computer prediction of reforestation of Rung Sat mangroves with and without planting by man. Woodcutters harvest 3% of forest each year. Productivity of the forest is 16 tons per acre per year (1360 gms per m^2 per year).

REFERENCES

Brouillard, K. D., 1970. Fishery Development Survey. South Vietnam. (Bureau of Commercial Fisheries, Department of the Interior) AID Project PIO/T 730-317-3-9190276, Saigon.

Chapman, V. J., 1966. Some Factors Involved in Mangrove Establishment. Scientific Problems of the Humid Tropical Zone Deltas and their Implications. UNESCO.

Davis, J. H., Jr., 1940. The Ecology and Geologic Role of Mangroves in Florida. Papers from Tortugas Laboratory, Vol. XXXII, Carnegie Institution of Washington Publ. No. 517, Washington, D. C.

Loftas, Tony, 1970. Fishery Boom for South Vietnam. New Scientist 46(700). London.

Macnae, W., 1966. Mangroves in Eastern and South Australia. Australian Journal of Botany 14(1).

Moquillon, C., 1949? La Forêt de Paletuviers de la Pointe de Camau. Rapport, Inspecteur principal de la classe des Eaux et Forets de l'Indochine, Saigon.

Noakes, D. S. P., 1955. Methods of Increasing Growth & Obtaining Natural Regeneration of the Mangrove Type in Malaya. Malayan Forester 18.

Rollet, B., 1962? Note sur la Végétation du Viet-Nam au Sud du 17è Parallèle Nord. (Trans. Defense Mapping Agency, Topographic Center, November 1972).

Shindo, Shigeaki, 1973. General Review of the Trawl Fishery and the Demersal Fish Stocks of the South China Sea. FAO Fish. Tech. Paper (120).

Viet-Nam Statistical Yearbook, 1971. National Institute of Statistics, Ministry of National Planning and Development. Republic of Viet-Nam.

Vu Van Cuong Humbert, F.S.C., 1964. Flora and Vegetation of the Mangrove of the Region Saigon Cap Saint Jacques, South Vietnam. Thesis presented to the Faculty of Sciences of the University of Paris (in French).

Walker, F. S., 1938. Regeneration of Klang Mangroves. Malayan Forester 7.

Watson, J. G., 1928. Mangrove Forests of the Malay Peninsula. Malayan Forest Records No. 6. London.

V. EFFECTS ON SOILS

Our studies on soils fall into two categories: (1) on persistence and disappearance of herbicides, and (2) on changes in soil properties and processes which may affect nutrient storage of a soil. They were done in South Vietnam, Thailand, and the Philippines.

A. Persistence and Disappearance of Herbicides

How long will a herbicide that has been introduced into the environment persist, how soon will it disappear? This is an obvious question, particularly when herbicides have been used at levels considerably higher than are usual in agricultural practice. There are also ecological implications. Where effects of defoliation persist, as in the mangrove, one wants to know whether this is because the herbicides have remained active, or because other changes were induced by the herbicides even though the latter themselves may have disappeared.

The Committee approached the problem of herbicide persistence in two ways: (1) by collecting and subsequently analyzing soil samples (and a few water samples) from areas which had been sprayed during the war, as far as possible selecting sites which had received particularly high doses; and (2) by spraying the soil surface with herbicides at known rates after it had been cleared of all vegetation, and then studying the change in concentration of the compounds over a period of time. The second approach was necessary because the number of samples that could be obtained in heavily defoliated areas was limited by security problems. Also, the Committee started its work a year and a half after the cessation of large-scale defoliation, and it seemed essential to observe the early stages of the behavior of the herbicides in the soils of SVN and similar regions.

The spraying equipment used was calibrated to apply the volume of liquid per unit area required and to give as uniform coverage as possible. Checks of actual dosages applied, determined by chemical analysis, verified the accuracy of our application.

Samples were taken either from the soil surface to a depth of 5 in. (12.5 cm) with metal cans, or with special samplers 30 or 36 in. (75 or 90 cm) long. The latter samples ("cores") were usually divided by depth into two or three sections. The total number of soil samples analyzed was about 750. Herbicide residue levels were determined either chemically or by "bioassay." Chemical determinations were carried out with the most up-to-date techniques for residue analysis (electron capture gas chromatography). Most of the analyses were done at the Huntingdon Research Centre in England, and selected samples were cross-checked at the Gulf South Research Institute, New Iberia, Louisiana. In the mangrove soils and in all samples with low residue levels, near the detection limit, the agreement between the two determinations was satisfactory, but in forest soil samples with higher levels, the GSRI values were considerably lower than the HRC values. In the following, we use the HRC results as their control tests (samples taken immediately after spraying) were very close to the theoretical values. The results are here expressed as pounds of herbicide (acid equivalents) per unit surface area (acre). Three gal./acre of Orange correspond to 12 lb/acre of 2,4-D and 13.8 lb/acre of 2,4,5-T; 3 gal./acre White to 6 lb/acre of 2,4-D and 1.6 lb/acre picloram. The concentrations resulting in soil and water from these application rates are given in Table II C-1. The bioassay techniques consisted of sequential plantings of various crop species, or in the case of mangrove forest soils, of seedlings of mangrove species, and subsequent observations on the development of any herbicidal symptoms.

(1) Analysis of Soil from Areas Sprayed during the Military Herbicide Operations

Soil samples from areas sprayed during or in connection with the military herbicide operations were obtained in two sites in Thailand near Pran Buri, and in four locations in SVN. The Thai sites were:

(a) An experimental forest plot that had been sprayed by aircraft in 1965 with 9.1 lb/acre Orange and 0.5 lb/acre picloram. (Eight samples were collected in September 1971.)

(b) The "Calibration Grid" which had been used for calibrating aerial herbicide spray equipment, and the center of which had received truly formidable amounts of herbicide in 1964-65: ca. 840 lb/acre 2,4-D, 960 lb/acre 2,4,5-T, 57 lb/acre cacodylic acid, and 20 lb/acre picloram. (Eight samples were collected in September 1971.)

The locations in SVN were:

(a) A "dump site" in the Di-An District, Bien-Hoa Province, on which the entire load of an airplane (1000 gallons Orange) had been released in December 1968 from a height of 1800 ft (540 m), an altitude over ten times higher than in regular herbicide missions. The location of this dump was confirmed by villagers. (Five samples were taken in October 1971.)

(b) One inland forest site near Cau Muoi-Mot, ca. 8 miles or 11 km northeast of Dong-Xoai, Phuoc-Long Province which had been sprayed once with White and once with Orange in 1968-69. This is the same site on which studies of the condition of the forest on the ground were made and soil samples taken for nutrient content analyses (Section IV B and V B). (Four samples were collected in October 1971.)

(c) Five different mangrove sites (see map, Fig. IV C-5--Study Sites 1, 5, 7, 8, and 9) in the center of the Rung Sat Special Zone which had been sprayed quite heavily. Herbicide mission records indicate that between 1965 and 1968 one of the sites (No. 1) received about 86 lb/acre 2,4-D, 79 lb/acre 2,4,5-T, 3 lb/acre picloram and 9 lb/acre cacodylic acid, and possibly more. (Three surface samples were taken in October 1971, 17 core samples were taken in October 1971 and March and August 1972.)

(d) Two sites in the mangrove of the Ca-Mau Peninsula. One of these, immediately outside Nam-Can Naval Base (see map, Fig. IV C-8) had been sprayed with unknown amounts of Orange. The other (Site 2 on the map, Fig. IV C-8) about 3 miles (5 km) to the north northeast had been the target of a Purple mission in 1962 (not shown on that map) and an Orange and two White missions in March-April 1970, a year and a half before sampling. (Three samples each were collected in October 1971.)

The results were briefly as follows:

(a) Of the six samples (about 26 to 32 in. = 65 to 80 cm deep) from the Pran Buri Calibration Grid, all contained picloram at 0.24 to 1.09 lb/acre; four contained 2,4,5-T at 0.06 to 1.35 lb/acre; and two contained 2,4-D at 0.16 and 0.19 lb/acre[a]. The higher picloram and 2,4,5-T levels are sufficient to cause severe damage and death in many broadleaf plants. Except in one sample, which contained high levels of picloram throughout its whole length, high levels of both herbicides were limited to the uppermost part of the cores, i.e. the top 10 or 20 in. (25 or 50 cm) of the soil.

(b) Of a total of 17 core samples (nominal length, 30-36 in. or about 75-90 cm) of Rung Sat mangrove soils, 11 contained 2,4,5-T in at least one of the parts of a three-section core. Two out of three surface samples also contained measurable quantities of 2,4,5-T. Of all 20 samples, four contained picloram, usually in all sections. The levels of 2,4,5-T ranged between 0.02 and 0.24 lb/acre (detection limit in different analyses, 0.006 to 0.04 lb/acre), those of picloram from 0.002 to 0.01 lb/acre (detection limit, 0.001 to 0.008 lb/acre). On the basis of published information, for a combination of certain soils and sensitive species, these quantities may be expected to cause herbicide symptoms but they are generally at the lower limit of effect.

(c) No herbicides were detected in the soil samples from the experimental forest plot at Pran Buri, the Di-An dump site, the Dong-Xoai forest site, and the two Ca-Mau mangrove sites (detection limits: 2,4,5-T, 0.005 lb/acre; picloram, 0.001 lb/acre).

(2) Analyses of Water

Some water samples collected in August 1972 from the lower part of the main shipping channel to Saigon (Song Dan-Xay, Song Dong-Tranh) were analyzed for picloram (sampling sites see map, Fig. IV C-5). Suspended sediment (mostly soil) was separated from the water by filtration, and the

---

[a] The 2,4-D was found in two samples taken from a site considered as being outside the perimeter of the Calibration Grid.

two fractions analyzed separately. No herbicide was found in the filtered water (detection limit 0.001 ppm), but the sediment of four out of eight samples contained amounts ranging from about 0.07 to 0.03 parts per billion if computed for the original volume of water, and from about 2.2 to 0.8 parts per million of dry weight of sediment. If all the herbicide in the sediment were to become available in the water, the levels would be far below the dose known to affect even the most sensitive species, but if only the sediments are considered the levels are somewhat higher than those found in the Rung Sat soil (maximum 0.01 lb/acre = 0.05 ppm). Herbicide in water is usually associated with suspended material if present, and turbid water may contain more herbicide than clear water, but the relatively high picloram content in the Rung Sat sediment is unexpected.

(3) Experiments on the Behavior of Herbicides in Tropical Soils

Experiments on the persistence of herbicides in tropical soils were carried out (a) on agricultural sites in the Philippines (Alabang near Manila) and in SVN (Ban-Me-Thuot); (b) forest soils in the Philippines (near Los Baños) and SVN (Ban-Me-Thuot); (c) mangrove soils near Vung-Tau. In all cases, the soil was cleared of vegetation by hand and was sprayed with 3 gal./acre Orange or White. Additional plots at Ban-Me-Thuot and Alabang received 1 gal./acre and 1/3 gal./acre of each agent.

In the agricultural experiments, persistence of herbicide effects was determined by planting rice, maize, sorghum, sweetpotato, mung bean, peanut, and soybean as test plants at intervals after spraying. The main criteria used were the weight of plants after four to five weeks of growth, and presence or absence of morphological symptoms characteristic of the herbicide in question, such as discoloration and distortion of the leaves, curling of the leaf margins, and curvature of stems and petioles. In the experiment with rice in the Philippines the plants were grown to maturity and the yield in threshed seeds was used to determine herbicide effects if any.

In forest soils, the herbicide levels were determined chemically, and in mangrove soils both chemically and by bioassay, making sequential planting of seedlings of two mangrove species. The mangrove experiment was done in two different ways. In one series, a relatively large area (174 by 96 ft or 50 by 30 m) was cleared, sprayed, and planted; in the other, small (one square meter or about 10.76 ft^2) plots within the forest were used so that the seedlings developed in a relatively undisturbed mangrove environment.

The principal results may be summarized as follows:

(a) The effects of herbicide residues persisting in the soil on field and vegetable crops disappeared after different periods of time, depending on the crop. Data for the application rate of 3 gal./acre are shown in Table V A-1, with lower rates (1 and 1/3 gal./acre) disappearance was, as to be expected, at least as fast and generally faster. In cereals (rice, maize, sorghum) the effects disappeared more rapidly than in broadleaf crops (sweetpotato, legumes). Effects of White on sensitive species

Table V A-1. Time in weeks between herbicide application to the soil and the first planting in which no herbicide effects were observed.

Agent, crop	Philippines Experiment: No effects on plant growth	Philippines Experiment: No morphological symptoms	Ban Me Thuot Experiment: No effects on plant growth	Ban Me Thuot Experiment: No morphological symptoms
Orange, 3 gal./acre				
Maize	4	4	4	4
Rice	6	6	10	10
Sorghum	4	4	10	10
Sweetpotato	15	15	10	10
Mung bean	4	15	17	17
Peanut	15	15	10	17
White, 3 gal./acre				
Maize	15	15	10	10
Rice	3	3	10	10
Sorghum	15	15	>10[a]	>10[a]
Sweetpotato	15	24	24	31
Soybean	--	--	24	31
Mung bean	15	24	31	31
Peanut	15	24	24	>31[a]

[a] Experiment discontinued after this planting.

persisted longer than effects of Orange; the difference is very probably due to the greater persistence of picloram, a component of Agent White. These results are in very good agreement with extensive general experience on persistence and disappearance of these herbicides in soils of temperate climates, and also with the much more limited experience with soils of warm climates. It appears that at the very latest one year after application of 2,4-D, 2,4,5-T, and picloram at the doses used in herbicide missions even highly sensitive crops such as legumes can be safely planted on sprayed soil. In the case of 2,4-D and 2,4,5-T and of less sensitive crops such as cereals the waiting time after herbicide application is considerably less.

?

(b) When the herbicides were applied during the dry season, they persisted in the soil without apparent loss until the onset of the wet season. Disappearance is thus dependent on a minimum water content in the soil.

(c) In forest and mangrove soils, the levels of the herbicides dropped, at first very rapidly, then more slowly, and by the end of the experiments (about 150 to 250 days) were near or below the chemical detection limit (0.02 to 0.03 lb/acre for 2,4,5-T; 0.002 lb/acre for picloram) and the limit of biological activity. An example is shown in Fig. V A-1. In agreement with these findings, the forest sites revegetated rapidly; the vegetation included highly sensitive plants. The disappearance of 2,4,5-T and picloram followed quite a similar time course, but since the initial dose of picloram was much less (1.6 lb/acre versus 13.8 lb/acre for 2,4,5-T) this means that the persistence of picloram was greater. The disappearance of the herbicides is mainly attributable to activities of microorganisms. In laboratory experiments, four soils from SVN, including mangrove soils, were found to be capable of degrading 2,4,5-T to carbon dioxide; the process exhibited similar characteristics to soils from temperate regions.

(d) Mangrove seedlings planted at different times after spraying the soil with herbicide became established as well as seedlings on unsprayed soils, nor were there any differences in growth (height) (Table V A-2). This was even true of plantings made as early as three weeks after spraying. The soil still contained measurable herbicide quantities at three weeks (see Fig. V A-1), and some of the seedlings planted on White-treated soil showed some picloram symptoms, but most of them recovered and became undistinguishable from control seedlings.

(e) Survival in the first plantings on the large cleared mangrove plot (experiment A in Table V A-2) was quite poor because the seedlings had been stored for some days and were in unsatisfactory condition. For later plantings (and all plantings on the small plots) seedlings collected on the day of planting were used, and survival was considerably better. However, even if this difference in seedling material is taken into account, the survival of the mangrove tree seedlings was much better on the small plots made in an otherwise intact mangrove than on the much larger plot that had been cleared of all vegetation (Table V A-2, compare experiments A and B)[a].

---

[a] Walsh <u>et al</u>. (1973) have recently reported experiments on the effect of

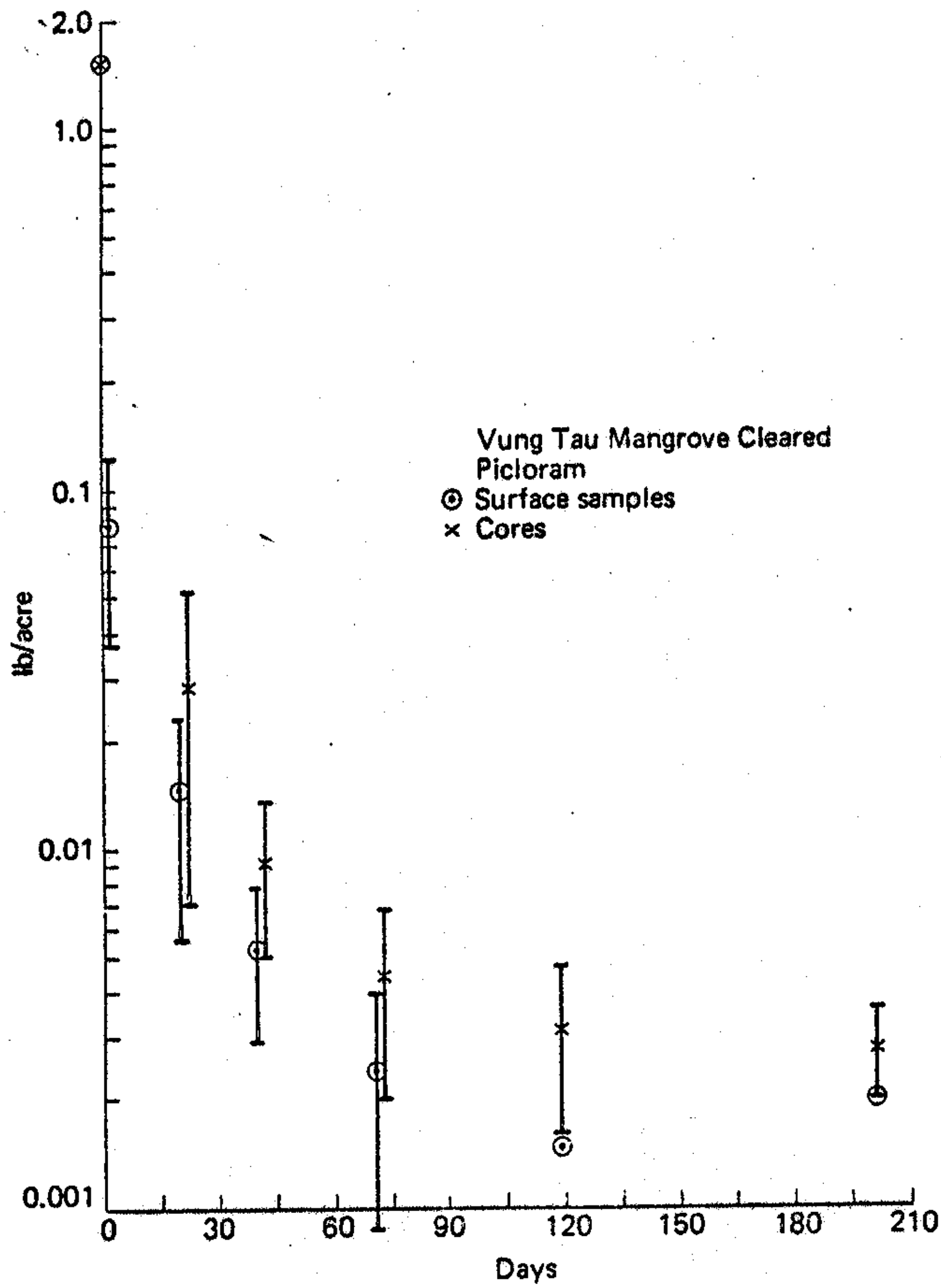


Fig. V A-1. Disappearance of picloram from mangrove soil cleared of vegetation. Application rate 1.6 lb/acre. Surface samples taken with 5 in. high metal cans, cores with a soil sampler 30 in. long, but the cores were mostly shorter because of compression of the soil during insertion of the sampler and removal of the core from the latter, and because of occasional loss of part of the core. Ordinate = remaining herbicide in lb/acre; abscissa = time after application of herbicide to soil. On vertical bars the x or the o represent mean values, the upper and lower end points of the vertical bars represent 95% confidence limits. Note that the ordinate is on a logarithmic scale which tends to minimize the differences.

Table V A-2 Survival and growth of seedling of *Rhizophora apiculata* on mangrove plots treated with Agent Orange and Agent White at a rate of 3 gal./acre.

A. Experiment on large cleared area

Observation (Weeks after soil treatment)	Seedlings planted 3 weeks after soil treatment			Seedlings planted 6 weeks after soil treatment			Seedlings planted 10 weeks after soil treatment			Seedlings planted 17 weeks after soil treatment		
	Control	Orange	White	Control	Orange	White	Control	Orange	White	Control	Orange	White
29 weeks: percent survival	4.7	4.2	2.7	5.5	5.3	3.3	7.7	8.7	6.3	18.7	18.5	21.7
35 weeks: percent survival	3.8	3.0	2.6	3.0	2.5	2.3	7.3	4.0	7.0	13.8	10.8	19.5
50 weeks: percent survival	3.0	3.0	1.6	1.0	2.5	2.7	6.7	3.0	3.0	10.4	6.0	10.7
height in inches	NR	NR	NR	NR	NR	NR	16.2	15.5	16.4	14.8	14.8	16.6

B. Experiment with small plots in undisturbed mangrove

Observation (Weeks after soil treatment)	Seedlings planted 3 weeks after soil treatment			Seedlings planted 6-1/2 weeks after soil treatment			Seedlings planted 12 weeks after soil treatment		
	Control	Orange	White	Control	Orange	White	Control	Orange	White
12 weeks: percent survival	76.7	84.1	79.1	87.5	95.0	94.2	--	--	--
19 weeks: percent survival	70.0	81.7	80.8	84.2	89.2	90.0	94.1	85.8	82.5
34 weeks: percent survival	71.6	70.8	79.1	74.2	90.8	89.2	78.3	85.0	71.7
height in inches	14.4	13.4	14.1	NR	NR	NR	16.5	15.8	15.9

The number of replicates in experiment A was 4 to 6; the number of plants per replicate was 25. In experiment B there were 40 plants in each of 3 replicates.

NR = not recorded

Height = total height in inches from soil surface to tip of topmost leaf.

(4) Agent Blue

The Committee did not undertake studies on persistence, or the lack thereof, of cacodylic acid, the active ingredient of Agent Blue. Analyses of soil from areas that had been sprayed with Agent Blue during the military use of herbicides at least a year and a half after that use had been terminated, and experiments of the kind we conducted with Agents Orange and White appeared to be equally unrewarding for the following reason. Ar enic is a natural constituent of soil, water, minerals, plants, and animals. The average content in soil is about 5 ppm, with variations from 1 to 40 ppm, in natural fresh and sea water between 0.003 and 0.05 ppm. Crystalline rock contains on the average 2.0 ppm, table salt 2.71 ppm, most plants in their edible parts between 0.1 and 1.0 ppm, but sometimes going up to about 3 ppm and higher (dry weight basis). Fish may contain between 0.2 and 15 ppm, shellfish around 1.5 to 3 ppm. (Data as elemental arsenic; from Liebig, 1966, Schroeder and Balassa, 1966; anon., 1971; and Frost, 1973). Arsenic undergoes a cycle in nature; in an agricultural ecosystem this involves input with fertilizers and arsenic herbicides, uptake by the plant and consumption by the animal, release by plant and animal, binding by and release from soil transfer between soil and water, etc. Although the pentavalent (arsenate) form is the more stable one and generally tends to accumulate, conversion to the trivalent (Arsenite) form may also occur when conditions favor reduction, as, e.g.,

---

Tordon 101, a herbicide formulation similar to Agent White, on seedlings of Rhizophora mangle. The formulation was added to estuarine mud in plastic boxes at the rates of 0.39, 3.93, and 39.3 lb/acre 2,4-D and 0.14, 1.43, and 14.3 lb/acre picloram, and seedlings were planted three days thereafter or later. The lowest dose used retarded development but caused no death; the two higher doses resulted in marked disruption of growth and subsequent death. The intermediate dose is of the same order as used in the herbicide operations in SVN (6 lb/acre 2,4-D and 1.62 lb/acre picloram) and seems to have been considerably more toxic than in our experiments at Vung-Tau. There are, however, major differences between the conduct of the two investigations. Firstly, different species of Rhizophora were used. Secondly, Walsh et al. used a closed system and a constant environment (constant temperature; light from fluorescent lamps for 12 hours a day) whereas at Vung-Tau it was an open system subject to fluctuations in tides, water table, and weather. Thirdly, planting at Vung-Tau was made at greater intervals after herbicide application to the soil, and interpolation in our decay curves indicates that at the time of the first planting (3 weeks) the levels of 2,4,5-T and of picloram in the soil of the microplots were about 0.7 and about 0.2 lb/acre, respectively. If one considers that the initial rate of 2,4,5-T (that in Agent Orange) was about twice that of 2,4-D in Agent White, and that 2,4-D most probably breaks down more rapidly than 2,4,5-T, the amount of herbicides left in the soil at our first planting was equal to or somewhat below the lowest dose used by Walsh and his colleagues.

in anaerobic soils. To determine, years after the fact, whether arsenic found in soils of herbicide-sprayed areas came from the herbicides, from other sources, or was present in the soil prior to the sprays seemed an impossible task. Analyses of a small number of samples of rice, fish and shellfish, a worm, and water and soil collected in or near a community in the Rung Sat which had been exposed to at least one Agent Blue mission between 1964 and 1969 gave arsenic levels within the normal ranges for such materials (see Section VII C).

As regards persistence of effects of cacodylic acid deposited on soil, available evidence indicates that it is considerably less than that of 2,4-D, 2,4,5-T, and picloram. On January 27, 1972, some members of the Committee made an overflight of the Song-Re Valley, Quang-Ngai Province, which had been sprayed with Agent Blue August 9, 1970. They observed extensive rice fields and some vegetable plots all of which, as far as they could be judged from a low-flying plane, appeared normal.

(5) <u>Conclusions</u>

Extent and detail of our sampling for herbicide residue determinations were considerably greater than in many previous studies, and represent a significant contribution to the knowledge of herbicide behavior in tropical soils, including mangrove soils where, to the best of our information, the problem has not been studied before. Obviously, the sampling design could have been further improved. For example, it would have been very desirable to get soil samples from the heavily sprayed inland forests of War Zones C and D, and to conduct persistence experiments with the alluvial soils of the Mekong Delta. Nevertheless, considering the distribution of samples selected in areas sprayed during the war and the diversity of soils represented in our own experiments, our results have considerable internal consistency, and agree very well with data from the literature.

The behavior of herbicides in the soils of SVN, and soils of similar tropical regions, appears similar to that in soils of temperate regions. Herbicide levels capable of causing severe damage to many plants were found only in the Pran Buri Calibration Grid--a unique site as it had received amounts of herbicides far higher than ever applied in SVN. Successful replanting is possible even in areas which received heavy military herbicide spraying, in no more than a year after the last spray mission and usually in much less time. The main conclusion of this part of our studies is that the persistence of herbicide residues in the soils of SVN is not a significant factor in subsequent growth of vegetation. Claims that the herbicides used in the herbicide operations have rendered the soil permanently "sterile," i.e. unfit for any plant growth, are not supported by our chemical and biological studies of herbicide persistence in the soils of SVN and are contrary to world-wide experience with the herbicides used.

Our data, taken in their entirety--that is, both those from areas sprayed during the military herbicide operations and those from our own experiments--offer little evidence for extensive vertical movement of the herbicides. The most striking case in this respect is the Pran Buri Calibration Grid which consists of sandy soil generally prone to leaching, and was literally drenched with 2,4-D and 2,4,5-T but where their residues were nevertheless limited mostly to the upper 10 to 20 in. (25 to 50 cm). Picloram, which is a more "mobile" compound (see Section II C[1]), was present also in greater depths, but mostly only in small amounts.

An interesting observation was made on the survival of mangrove seedlings on a relatively large area, cleared *in toto* of vegetation, as compared to small plots laid out in an otherwise intact mangrove. Under the latter conditions, and even when differences in the quality of the seedling material had been taken into account, survival was markedly superior, indicating that removal of vegetation created conditions unfavorable to the reestablishment of mangrove. These conditions are not, however, due to persistence of the herbicides, and they do not operate in all mangrove sites since survival of seedlings planted on a denuded area in the Rung Sat was as high as 50-80 percent (see p. IV-110).

REFERENCE

Walsh, G.E., R. Barrett, G.H. Cook and T.A. Hollister, 1973. Effects of herbicides on seedlings of the red mangrove, *Rhizophora mangle* L. BioScience 23:361-364.

B. Effects of Herbicides on Soils of South Vietnam

Since soils are an integral part of terrestrial ecosystems, changes in the vegetation may cause changes in the chemical and physical properties of these soils, and in the processes which underlie these properties. In the case of SVN there have been reports that the defoliation and killing of vegetation in the military herbicide operations may have caused adverse effects on soil fertility and irreversible deleterious changes such as laterization and soil erosion.

The purpose of our studies was to document the possible changes that may occur to soil due to herbicide treatment of the vegetation. The data presented are the results of several months of field work in various areas in SVN and Thailand, with more than 3600 laboratory analyses on 304 soil samples. Soils in sprayed and non-sprayed areas were compared and soil samples were obtained for standard physical and chemical measurements in the laboratory; the results were then used to test hypotheses about the effects of defoliation on soil properties. The elements in the soil that were investigated were total carbon, total nitrogen, and the exchangeable cations: calcium, magnesium, potassium, sodium, and manganese. Phosphorus was determined in soil water extracts. In addition, the pH of the soil and its cation exchange capacity[a] were determined. The analyses were carried out using standard analytical techniques used in soil science, and the data have been calculated as total storage of the elements in the top 5 cm (2 in.), and as the storage of elements in the total soil profile to the one-meter (3.3 ft) depth, expressed in grams per square meter (g/m^2).[b] Soil properties are known to vary widely, even in a limited area and all sample areas represented soils with a range of properties. Therefore, soil samples were taken to represent surface variability of the soil and to characterize the variation with depth of the soil; vegetation samples were taken to evaluate the vegetation weight (biomass) and the amount of nutrient elements stored in the vegetation on representative areas.

---

a Cation exchange capacity is the capacity of the soil to hold elements in their positive charged or cation form. This is the most important storage capacity in tropical forest soils for such elements as calcium, potassium, and magnesium; but a common fertility problem is the saturation of this capacity with elements that may be toxic or not required by vegetation such as hydrogen and aluminum.

b One square meter = about 10.76 square feet; one gram = about 0.035 oz. Multiply grams per square meter by 8.9 for pounds per acre.

(1) Inland Forests

The study was divided between the effects of defoliation on the soils of inland and of mangrove forests, corresponding to the two main types of affected vegetation. Sites in inland forests were in 12 locations in Thailand and in one in SVN (near Dong-Xoai, Phuoc-Long Province). The locations represented Open and Closed forest (see Section II E). A considerable range of soil types (podzolic, regosol, latosol, laterite, and alluvial), various soil histories (primary and secondary forest, secondary succession to bamboo, an old village reserve forest) and various vegetation types (*Dipterocarpus alatus*, *Hopea-Shorea*, mixed dipterocarp, *Quercus-Castanopsis*, etc.)

Fertility Properties of Closed Forest

The surface soils of the Closed Forest are more fertile in some respects than those of the Open forest (Table V B-1). There is more organic matter (represented by carbon content), more nitrogen, and a greater cation exchange capacity for storing nutrients and other competing cations. However, soils associated with the Open forest tended to have more calcium and magnesium stored in them, but were lower in potassium storage. The soil in the Closed forest, having a greater stored quantity of carbon and nitrogen, and a greater cation exchange storage capacity should have a larger capacity to buffer changes in the soil nutrient status brought on by changes in the forest cover, including those by defoliation.

A large proportion of the total site fertility in tropical forests may be stored in the vegetation, relative to the soil. An assessment of two typical sites in the Closed forest showed vegetation storage of nutrient elements in the forest vegetation relative to the forest soil was highest for potassium and phosphorus, and lower for nitrogen. The foliage and woody portions of an old forest in Thailand, on an acre basis, had 1,139 lbs of nitrogen, 172 lbs of phosphorus, and 1,371 lbs of potassium. The proportion of nutrient elements in the Closed forest foliage may range from more than 20 percent of total forest storage (soil + vegetation) in the case of potassium, to one to six percent in the case of nitrogen. Hence, a critical aspect of the effect of defoliation on the fertility of the site, and of the soil in particular, would be the disposition of the nutrient elements contained in the foliage subject to defoliation. These will be returned to the soil, where they can be either stored and used by plants or lost by leaching. The situation will be more critical in the case of an element like potassium of which a large proportion of the total in the entire ecosystem is stored in the foliage.

Table V B-1. Storage of nutrient elements in the surface 5 cm of soil of unsprayed Closed and Open forests and of mangrove. (Average values based upon all samples in each category)

Element	Closed Forest	Open Forest	Mangrove
Carbon (g/m^2)	287	184	333
Nitrogen (g/m^2)	23	9	16
Carbon/nitrogen ratio	12	20	21
Cation exchange capacity[a]	1.10	0.81	1.88
Calcium[a]	0.28	0.60	0.40
Magnesium[a]	0.13	0.21	1.23
Potassium[a]	0.05	0.03	0.12
Sodium[a]	0.005	0.005	2.02
Manganese[a]	0.03	0.02	0.01
pH	4.5	6.1	5.5

[a] Equivalents per square meter to 5 cm depth.

The fate (whether stored in the soil or lost) of nutrient cations entering the soil as a result of defoliation depends upon the cation exchange storage capacity of the soil. In addition, the adsorption of a cation such as potassium may be reduced by other elements added from the foliage or already present on the soil exchange complex. The following cation quantities expressed in gram equivalents per square meter of soil surface to a depth of one meter are characteristic of the Closed forest:

		Cation Exchange Capacity	Calcium	Magnesium	Potassium
Vegetation:	Foliage		1.1-0.2	1.0-0.2	1.3-0.2
	Wood		8.7-5.0	1.4-0.8	2.6-1.5
	Total		9.8-5.2	2.4-1.0	3.9-1.7
Soil (average)		59.1	7.0	3.6	2.1

Thus, if the foliage is removed from the trees and deposited on the soil, eventually from 3.4 to 0.6 gram equivalents of cations will be entering the soil cation exchange complex with a capacity of 59.1 gram equivalents. This soil exchange capacity is only partially saturated with 12.7 equivalents of calcium + magnesium + potassium (very little sodium is present in these soils) and these represent only 21 percent of the cation storage capacity of this average Closed forest soil. These data indicate sufficient storage capacity on the exchange complex to adsorb the 3.3 to 0.6 equivalents of exchangeable cations that will be released from the foliage drop in the defoliated forest. However, there is a grave risk of losing the potassium if the levels of the other elements are too high in the soil, or in the recycling elements of the leaves shed as a result of defoliation.

Fertility Balance of Secondary Succession with Bamboo

When disturbance of a forest results in a secondary succession of bamboo the soil-plant fertility balance of the site is adversely affected. This is indicated by studies in an area in Thailand where bamboo had taken over a disturbed Closed forest. The analyses indicated a much lower vegetation weight, and correspondingly lower nutrient storage in the bamboo than in the forest which it had replaced. Also a large proportion of the nutrient elements were in the underground portions of the plants. These observations suggest that the bamboo maintains a lower reserve of nutrients on a site, and in a form that would be difficult to return to the soil unless an effective way of killing the underground parts and suppressing further bamboo growth is perfected.

Comparison of a Defoliated and Non-Defoliated Forest

A comparison of a defoliated and non-defoliated forest area was possible only in one case, a secondary forest in Thailand, at the former herbicide test site near Pran Buri. The defoliation treatment was applied in 1965 with 9.1 lb/acre Orange and 0.5 lb/acre of picloram, and no longer contained measurable quantities of herbicide (see Section V A). Significant differences in nitrogen and available phosphorus in the surface soil were noted. The available phosphorus content was in the sprayed site nearly one-half and the nitrogen content 10 percent less (nearly 80 lb/acre and 62 lb/acre, respectively [in the surface 5 cm]) than in the unsprayed site. The soil was more acid in the former than the latter site (pH 6.0 and 7.0, respectively). There were no statistically significant differences in the defoliated versus undefoliated areas in carbon, in exchange capacity, and in exchangeable calcium, magnesium or potassium. However, exchangeable sodium, even though low in both areas in absolute terms, was significantly higher in the defoliated area than in the non-defoliated one.

Laterization

Laterization is a process wherein lateritic soils are formed by the leaching of silica and the accumulation of secondary oxides of iron and manganese. Upon exposure to air, this material may harden into a durable, brick-like substance which inhibits vegetation growth. Concern has been expressed that this hardening of the soil of defoliated areas is one of the deleterious effects of the military herbicide operations in SVN.

The hardening of laterite material has to take place from an already existing lateritic soil that has developed to the stage where it can form hard laterite when exposed to drying and high temperatures. This occurs only on limited areas in the inland forests. Aerial observation, interpretation of aerial photos, information from South Vietnamese soil scientists, and limited ground observations in defoliated forest areas and of Rome-plowed roadsides indicate, however, that hardening of laterite on a major scale, which would be apparent as areas devoid of vegetation, has not taken place. Defoliation in inland forests evidently did not keep areas bare long enough to appreciably affect the process of laterite hardening, and if there are areas which have undergone laterization as a consequence of defoliation they are of minor extent. The worst case we observed was the so-called Calibration Grid near Pran Buri, Thailand, which had been used for calibrating herbicide spray equipment and had received about 840 lb/acre 2,4-D, about 960 lb/acre 2,4,5-T and smaller quantities of other compounds. It exhibited bare areas covered with a hard lateritic crust which, however, was not yet thick enough to prevent recolonization (see Fig. V B-1).

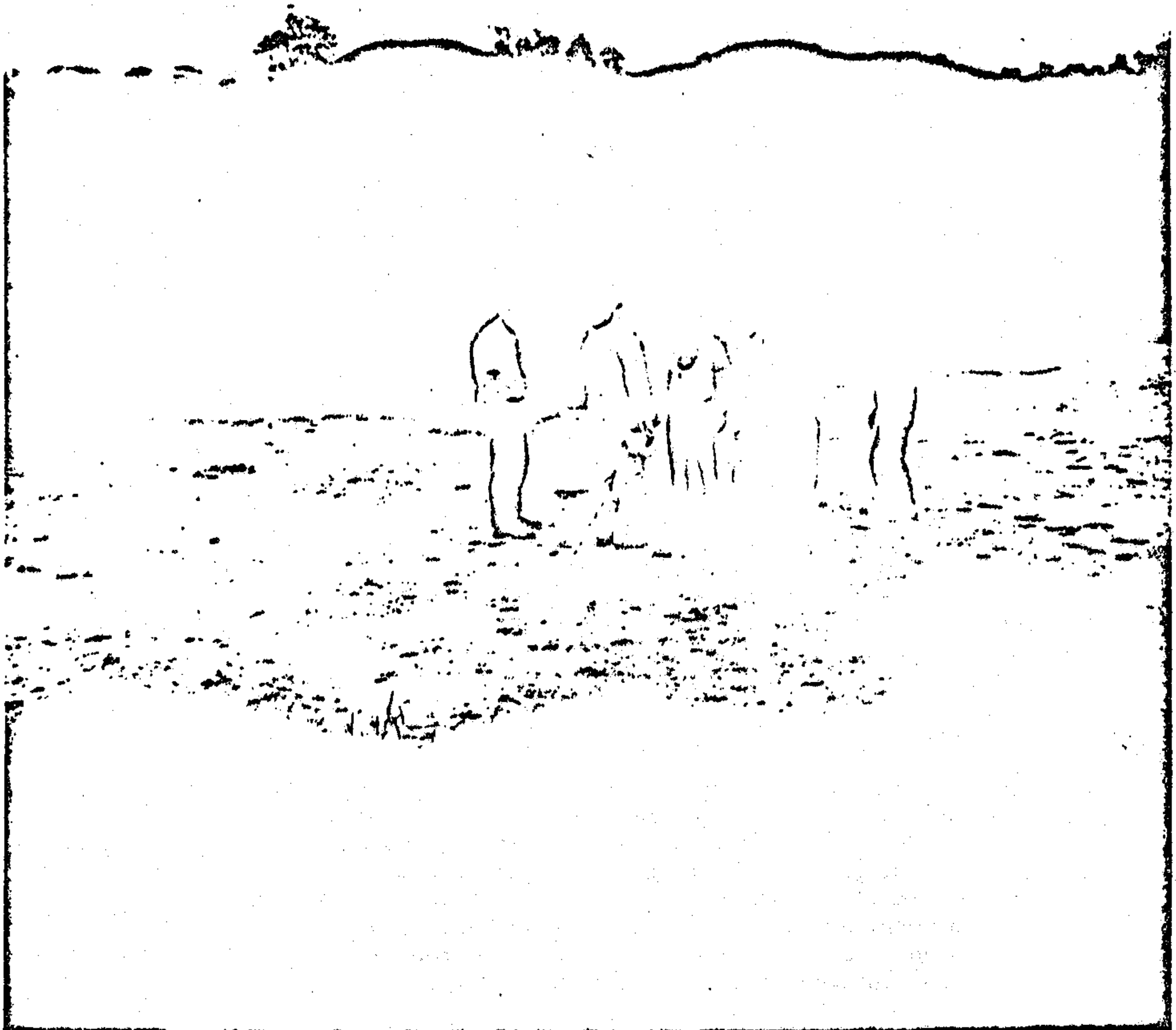


Fig. V B-1. Bare areas in the Pran Buri, Thailand Calibration Grid. Photo taken by Dr. Paul Zinke in September 1971.

(2) Mangrove Forest Soils

Soil and fertility studies in the mangrove were conducted in the Rung Sat Special Zone, in an area north of Vung-Tau, and in the Nam-Can area of the Ca-Mau Peninsula. Most of the mangrove soils in SVN were silts deposited by the Mekong and the Saigon rivers, with some peat deposits in basins on this delta material. The soil samples taken in the Rung Sat area were all from defoliated and now barren areas; those in the Vung-Tau area were from the center of the clearing made for the Committee's herbicide persistence experiments (see Section V A); those in the Nam-Can area were from both defoliated and non-defoliated mangrove forest, at sites located along a main canal northeast of Nam-Can, and at the west end of the Nam-Can airport. For comparison, a mangrove forest was sampled at Khlung, near Chantaburi, Thailand, an area that had not been disturbed by defoliation. The total number of locations was 14 with 146 soil samples. Total overall nutrient reserve in the mangrove forest, in both vegetation and soil, was determined at Vung-Tau and at the site near Chantaburi.

The average results of all analyses of the mangrove forest soils indicate some special characteristics of these soils, as compared to the other forests (see Table V B-1). The mangrove soils are moderately acid. The average pH of 5.47 is lower than that in the Closed forest soil but higher than that of the Open forest soil. The mangrove soils have more organic matter (as indicated by carbon content) with less nitrogen storage than Open forest soils, and a resulting higher carbon/nitrogen content than the Closed forest soils. The exchange capacity in the top five cm of the soil is markedly higher than in Open forest soils, and in this exchange capacity are retained higher quantities of exchangeable nutrient cations, and high amounts of magnesium and sodium are retained, as is to be expected due to the regular flooding with sea water.

Effects of Defoliation and Clear-Cutting in Mangrove Forests

The effects of defoliation were studied by comparing soil properties in a defoliated and a non-defoliated mangrove area northeast of Nam-Can (Ca-Mau Peninsula), and by soil analyses of six heavily defoliated, barren sites in the Rung Sat. For comparison, the effect of a clear-cutting treatment on soil characteristics was also studied, making use of the control (unsprayed) portion of the mangrove site near Vung-Tau which had been hand-cleared (and the cut vegetation removed) for the Committee's herbicide persistence experiments (Section V A).

The soil of the defoliated mangrove forest near Nam-Can was found to have slight increases in carbon, nitrogen, the carbon/nitrogen ratio and exchangeable calcium, and slight decreases in magnesium, potassium, sodium, and manganese, as compared to an adjacent non-defoliated mangrove forest. There was a considerable decrease in soil pH from 7.2 to 6.3; and a large increase in phosphorus content attributable to defoliation. The results are summarized in Table V B-2. This area had been defoliated with Orange and/or White about a year and a half before the soil sampling.

Table V B-2. Comparison of properties of surface soil (5 cm = 2 in) in defoliated and non-defoliated mangrove near Nam-Can, Ca-Mau Peninsula, and in bare areas of former mangrove in the Rung Sat.[a]

Treatment	Ca-Mau Defoliated	Ca-Mau Non-defoliated	Rung Sat Denuded
Carbon (g/m^2)	210	173	1688
Nitrogen (g/m^2)	15.3	14.8	86.8
Carbon/nitrogen ratio	14	12	19
Phosphorus as PO_4 (g/m^2)	7.7	5.9	NA[c]
Cation exchange capacity (equivalents/square meter)	2.2	2.2	10.7
Calcium[b]	0.56	0.51	2.5
Magnesium[b]	1.13	1.28	6.9[d]
Potassium[b]	0.16	0.21	0.6
Sodium[b]	2.09	2.64	9.8[d]
Manganese[b]	0.03	0.05	0.05
pH	6.32	7.18	6.1
Bulk density	0.98	0.94	0.16

[a] The defoliated area in Ca-Mau had been subjected to a Purple mission in 1962 and to one Orange and two White missions in 1970. The Rung Sat area received herbicides of the order given in Section V B.

[b] Equivalents per square meter to 5 cm depth.

[c] Not analyzed.

[d] Saturated due to ocean water.

Similar results were obtained from the clear-cut mangrove plots at Vung-Tau. Here, there was a very significant (at the one percent level) increase in bulk density, and decrease in pH as a result of clear-cutting the mangrove forest six months prior to the measurements. Nitrogen and magnesium storage in the soil of the clear-cut site was decreased (significant at the five percent level), and the quantity of available phosphorus was reduced by 50 percent (significant at the one percent level). This reduction in available phosphorus may present a tie-up in unavailable form at the lower pH which had resulted from clear-cutting the vegetation. These results indicate that the normal forest harvest operations in mangrove forests may produce effects on soil fertility properties that are similar to the effects of defoliation.

In soils from defoliated, denuded sites in the Rung Sat, there was nearly twice as much carbon and nitrogen as in soils from the intact mangrove near Vung-Tau (Table V B-2). The Rung Sat soils had a greater cation exchange capacity, and a larger amount of calcium and potassium on this exchange complex. One can conclude from this at least that the defoliated areas visited in the Rung Sat have soil fertility levels that are considerably higher than the non-defoliated mangrove forest at Vung-Tau and Ca-Mau. Alternative uses, such as tropical polders, should be a possibility for these lands.

<u>Summary</u>

Studies were made of forest soil in Southeast Asia that involved the effects of defoliation on soil properties related to soil fertility. These properties were content of carbon, nitrogen, exchangeable calcium, magnesium, potassium, sodium, and manganese. Also water soluble phosphorus, soil pH, and soil exchange capacity were determined. The study concentrated on 12 inland forest sites with 304 soil samples; and 14 mangrove forest locations with 146 soil samples. Vegetation and foliage storage quantities were obtained at 3 of the inland forest sites and at 2 of the mangrove sites.

An analysis of the variability of soil properties at any one location indicated that analyses of large numbers of soil samples would be needed to support or disprove any hypothesis regarding defoliation effects.

In the inland Closed forest areas it was found that the foliage subject to return to the soil by defoliation contained from 0.6 to 3.4 gram equivalent weights per square meter of basic elements such as calcium and magnesium. The soil had an available capacity to absorb 46.4 equivalents of these elements. However, despite this large capacity, there is a major risk of loss of potassium. Secondary succession of bamboo vegetation was found to have a lower fertility storage than the Closed forest. At one study site, with sufficient samples obtained to satisfy statistical conclusions, eight years after defoliation the

Closed forest soil was found to have 10 percent less nitrogen storage and a 50 percent reduction in water soluble phosphorus quantities and the soil was more acid than the soil in the adjacent undefoliated control area. Other fertility elements measured were not significantly changed. In mangrove forests areas studied, the defoliated area soils were found to have increased content of carbon, nitrogen, and water soluble phosphorus, and were more acid than the non-defoliated areas. However, the total nutrient content of soil in one defoliated area was considerably higher than that of soils in other non-defoliated mangrove areas.

The hardening of laterite of serious enough extent to render areas barren has not occurred extensively in defoliated areas of SVN. Presumably, this is because of the rapid regrowth of vegetation following defoliation.

VI. EFFECTS OF HERBICIDES ON ANIMALS

Little quantitative information is available about animal populations in SVN. There are no baseline data that would permit a comparison between prespray and post-defoliation population numbers.

Two studies were conducted to determine relative diversity and frequency of certain animals in herbicide treated and untreated mangrove. No studies could be carried out in the inland forest. One of the studies in the mangrove was concerned with mosquitoes, some of which are the carriers of malaria. The results are reported in Section VII A-3. The second study dealt mainly with animals (fish, plankton, molluscs) in the water of sprayed mangrove in the Rung Sat Special Zone and unsprayed mangrove near Vung Tau. A brief discussion of this subject is included in the section on mangrove forests (Section IV C).

Some perceptive responses of the Vietnamese people about effects of herbicides on animals are reported in the section on socioeconomic effects of herbicides on people (Section VII B).

VII. EFFECTS ON HUMANS

A. Biological Effects

Potential effects of herbicides on humans may be biological, socioeconomic, and psychological. Biological effects which could result from exposure to herbicides as to any chemical compounds possessing a certain biological activity include direct toxic effects of the chemicals or their contiminants or decay products, when ingested, inhaled, or deposited on the surface of the body. These effects could result in illness or death; or they could appear as alterations in reproductive performance, either in fetal wastage (miscarriages or stillbirths) or in birth defects such as cleft lip or cleft palate following exposure of pregnant women to herbicides or their contaminants; or they could consist in alterations of genes and chromosomes and in this case be transmitted to later generations. Less direct biological effects could result from herbicide-induced changes in man's environment, by favoring the propagation of disease organisms or the vectors (carriers) or reservoirs of disease organisms, such as mosquitoes or rats, and/or by decreasing the availability of food or other economic resources, thus leading to malnutrition or starvation and to changes in the social situation of the people. Psychological impact may be looked for in the perceptions of people exposed to herbicides, feelings people in SVN had about herbicides, their recollection of herbicide effects on people and on the environment.

Given the limitations of time, resources, and safety under which the Committee was working in SVN it was not possible to investigate whether all these potential effects had or had not occurred, nor was it always possible to separate effects of herbicides from the effects of the complex of war-related changes in recent years in Vietnam. However, we were able to detect certain medical-ecological, economic, and psychological effects on humans which had persisted beyond the time of spray and beyond the disappearance of the herbicides in most soils (see Section V B), and to initiate analyses of certain other potential medical effects. The report will progress from biological to socioeconomic and psychological effects. Also reported is a study of one community in the Rung Sat mangrove area where an attempt was made to obtain, in one place, an integrated ecological picture of herbicide and other war-related effects.

The toxic effects of the herbicides used in the Vietnam war including that of TCDD, the highly toxic contaminant of 2,4,5-T and hence Agent Orange, the most widely used agent in that war, have been discussed elsewhere in this report (Sections II B and C). Because of the absence of adequate medical records from the time and locations of the herbicide operations, the length of time which had passed since extensive herbicide spraying had been carried out, and the likelihood that direct toxic effects would be relatively transient, we could not conduct medical studies of any immediate toxic effects of herbicides in SVN. Perceptions and reports of people who had been exposed to herbicide sprays, or thought to have been, are summarized in later chapters of this section (B-2 and B-3). Near the end of our studies in SVN, we found a well-defined group of 45 to 50 Vietnamese military personnel who had been handling herbicides (transferring them from the containers in which they arrived, to other containers and to the aircraft) for many years and thus appear to represent a population, although a relatively small one, uniquely suited for studies of any long-term medical effects. That such studies should be made features as a recommendation of the Committee.

(1) Reproductive, Teratological, and Genetic Effects of Herbicides Used in SVN

Proposals or speculations put forward in previous publications included the following: (a) exposure to herbicides leads to chromosomal changes; (b) exposure to herbicides leads to an increase in fetal wastage (stillbirths, miscarriages); (c) exposure to herbicides leads to an increase in rates of congenital malformations including cleft lip with or without cleft palate, cleft palate, neural tube defects (spina bifida, anencephaly), and Down's syndrome (mongolism).

Literature on the relationship of herbicides to chromosomal changes, fetal wastage, and birth defects was examined, including studies reported from SVN and from elsewhere in the world, and a pilot study was initiated designed to collect data which would allow comparison within a population of hospitalized children to see if there was any correlation between history of herbicide spraying in the reported areas of residence of their mothers and the nature of their illness (congenital or non-congenital).

(a) Chromosomal Abnormalities

In a study from the DRVN (Ton That Tung et al., 1971; see Tables II and III) chromosomal abnormalities after exposure to herbicides were reported, based on a study of 179 persons who had lived in regions of spraying for from two months to four years or who were "direct victims of spraying," out of a total of 903 refugees from SVN who had moved to the DRVN. Exposure and medical histories were collected, and medical examinations were conducted, and reported symptoms of illness associated with spraying were recorded. Reports are given on examination of chromosomes of "normal persons" (no number given in tabulation), three "persons having lived in SVN but not yet victims of sprays," three "victims of sprays without apparent after-effects," three "victims of sprays with important after-effects 'asthenia, ocular lesions'," and three "children born of mothers who were victims of sprays." As compared with the unsprayed "controls" those sprayed were reported to have a higher frequency of chromosome abnormalities, mostly breaks or gaps. However, this study is inadequate in several regards: The frequency of breaks or gaps in the sprayed individuals was of the same order of magnitude as that reported for several North American "control" populations, for instance those used in studies on the possible chromosomal effects of LSD (Corey et al., 1970), whereas the control figures were much lower than those usually observed in control populations (ibid.). Furthermore, the types of abnormality reported were mostly not those expected from chromosome damage occurring some months or years previously. No attempt was made in this study to distinguish between herbicide exposure and other agents, such as viral infections, known to cause chromosome abnormalities, and the study is inadequate in terms of statistical requirements.

Studies in the U.S. on chromosomes of workers in a plant manufacturing 2,4,5-T indicated no increase in frequencies of breaks or other chromosomal aberrations in samples from 976 exposed workers. Controls were 1922 workers tested pre-employment, 2143 workers from another Dow plant, and data from literature (Kilian, 1973). A more critically controlled study would be desirable.

In conclusion, there is a lack of well-controlled studies on the chromosomal effects of TCDD, 2,4,5-T, and other herbicides in primates and exposed human beings, and these should be done. Furthermore, it appears that TCDD is a potent mitotic poison and possibly a mutagen in lower organisms. Studies should be done using modern methods of testing for mutagenicity in human cells to evaluate this potential hazard to man.

(b) Fetal Wastage

A U.S. Army medical team (Cutting et al., 1970) analyzed the records on stillbirths and hydatidiform moles in three Saigon and 22 provincial and district hospitals for the years 1960-1969 to establish any relation to exposure of women to herbicides. They concluded there was a decline in stillbirth rate, and no increase in malformation rates during this period which includes the years of heaviest herbicide operations.

Meselson et al. (1972) examined midwife record books and hospital records and concluded that the decline in stillbirth rate had occurred only in Saigon, while rates in the rest of the country rose from about 20 per 1,000 livebirths in 1962 to a peak of about 53/1,000 in 1967, and then declined again to about 37/1,000 in 1969. In Tay-Ninh Province, the northern part of which was heavily sprayed, they reported the stillbirth rate was 58/1,000 in 1968 and 101/1,000 in 1970. These are high rates as compared with the 37/1,000 reported in 1969 for SVN outside of Saigon, or the 18/1,000 reported by Emanuel et al. (1972) in six hospitals in Taipei.

An apparent increase in the number of patients with some particular birth defects, e.g., cleft palate without cleft lip, relative to other birth defects was noted by Meselson et al. (1972) to appear to have been associated with the periods of herbicide spraying. As shown in Table VII A-1, when the same data are expressed, instead, in terms of the frequency of each of several classes of birth defects per thousand unselected admissions to that hospital, the years of maximum incidences of various defects were quite inconsistent. Such a distribution does not support the suggestion that herbicide spraying may have engendered birth defects nor does the incidence of total malformations in the same population. It is regrettable that a sufficient body of reliable data concerning malformations per thousand births, from both sprayed and unsprayed areas, is not available. Additional information in this regard may become available from the still incomplete study, by the Committee, intended to correlate the incidence of birth defects in children treated in the Cho Ray Hospital with the exposure of their mothers to herbicide spraying during pregnancy.

Table VII A-1. Frequencies of selected malformations per 1,000 admissions to a Saigon Children's hospital. (Highest frequency underlined). From data in Le-Anh (1970)

	1962	1963	1964	1965	1966	1967	1968
Megacolon	9.2	6.9	<u>13.8</u>	9.9	7.9	13.7	8.6
Imperforate anus	17.6	<u>20.0</u>	17.9	17.6	13.6	15.5	10.3
Cleft lip + cleft palate	18.5	16.5	<u>40.6</u>	20.6	17.8	30.0	15.1
Isolated cleft palate	0.4	0	1.6	0.5	2.6	<u>5.5</u>	2.6
Neural tube malformations	2.7	1.7	2.9	2.4	1.5	<u>3.8</u>	3.4
All malformations	128.0	123.0	198.0	165.0	143.0	160.0	111.0
Total admissions	2612	1151	3127	4030	4553	4169	4974

(c) Committee Activities in SVN

Members of the Committee concerned with human effects planned a series of studies to investigate the relationships between spraying and reproductive failures. The objectives were to evaluate the feasibility of getting reliable information from hospital and vital statistics records on fluctuations in frequency of malformations that could be meaningfully related to herbicide spraying; to attempt identifying populations from sprayed and unsprayed areas that were otherwise comparable and from which data on malformation prevalence, chromosome breaks, etc., might be collected; to plan for and identify resources necessary to carry out the collection of such data; and to make recommendations concerning the feasibility and worth of such studies. It was also our intention to recheck the Tay-Ninh figures reported by Meselson *et al.* (1972). This and most of the other plans were frustrated by the North Vietnamese Spring 1972 offensive with heavy military action around Tay-Ninh city and greatly reduced security elsewhere in the country.

We attempted to check the general accuracy of stillbirth and malformation records as they might be related to systematic reporting errors. Several persons concerned with medical statistics in Saigon confirmed the fact that stillbirths might go unreported, or that liveborn children who died within a short time after birth might be reported as stillborn in order to avoid the necessity of filing two reports. This kind of underreporting would presumably vary inversely with the quality of medical services, and directly with the amount of social upheaval in the locality and it would be impossible to sort out effects possibly resulting from spraying from fluctuations due to these and other factors. With congenital malformations, one faces similar problems.

We confirmed the statement in the report by Meselson et al. (1971) that such malformations might not be recorded in the primary birth record or vital statistics for cultural reasons, since having a deformed child means loss of face to the parents. Thus anywhere but in a good maternity hospital data on frequencies of congenital malformations at birth may be untrustworthy, and good maternity hospitals are not likely to be found in areas of spraying.

If we assume a relationship between the amount of herbicide sprayed and birth defect rates, we would predict a rise in malformation rate paralleling, or if we assumed a time lag between time of spray and the appearance of birth defects (since teratogens ordinarily cause such birth defects as cleft lip and palate only early in pregnancy) somewhat lagging behind the increase in amount of herbicide sprayed. Depending on whether the teratogenic substance persists or accumulates, or whether it disappears rapidly, we would predict a continued high level or continued increase in malformation rates, or a decrease in relation to reduction and cessation of the herbicide operations.

In order to test these hypotheses we should compare reliable rates from the pre-spray period with rates from the spray and post-spray periods. Table VII A-2 was prepared from data in the Annual Reports of Tu Du Hospital, one of the major Saigon maternity hospitals, as far as these reports were available to us. Unfortunately, these data are inadequate for a rigorous test of a relation between herbicides and birth defects, for two reasons. First, there are too few records. We have data for only two of the heaviest spray years (1967, 1969), and have none for the years when herbicide operations were phased out and the post-spray years (1970 and following). Second, the total number of births for 1967, and perhaps for 1966, appears to be in error, the former being much too high in comparison with the preceding and following years. If the numbers of malformations are correct, this would give malformation rates which are too low for 1967 and possibly also for 1966.

Keeping these difficulties in mind, the only evidence of association between amount of spray and malformations in the Tu Du records is the increase in cleft lip and palate reported for 1969, to the highest level in the reported series. In contrast, the 1969 club foot rate is lower than for 1966 (and lower than 1967, if total births were erroneously reported for 1967), anencephaly rate in 1969 is up from the level calculated for 1967, but is lower than 1966, and the total malformation rate in 1969 is lower than in four of the seven years for which the Annual Reports are available. Thus, the data in the available Tu Du Annual Reports do not show a consistent relationship between amounts of herbicide sprayed and rates of malformations, but they are not sufficient for firm conclusions.

Table VII A-2. Malformations and Malformation Rates per 1,000 Births, from the Annual Reports of Tu-Du Hospital, Saigon (Highest frequency underlined).

Malformation		1962	1963	1964	1965	1966	1967	1968	1969
Cleft lip and palate	No.	20	32	29	32	37	36	NA	112
	Freq.	1.69	2.64	1.79	1.65	2.49	1.05	NA	<u>3.79</u>
Anencephaly	No.	18	12	24	28	42	20	NA	48
	Freq.	1.52	0.99	1.48	1.44	<u>2.82</u>	0.58	NA	1.62
Club foot	No.	NA	NA	NA	NA	7	8	NA	9
	Freq.	NA	NA	NA	NA	<u>0.47</u>	0.23	NA	0.30
All malformations	No.	123	125	142	115	166	144	NA	253
	Freq.	10.40	10.32	8.76	5.91	<u>11.16</u>	4.19	NA	8.56
Total births		11,831	12,111	16,218	19,452	14,875	34,345	NA	29,562

NA = not available or not appearing in tabulations.

On visiting the other major maternity hospital in Saigon, Hung-Vuong, we found that they were publishing an annual report, beginning in 1969, with a computerized system that provides data on many parameters, including rates of congenital malformation. The data we were given on that visit indicated frequency of major malformations rose from 57/13,244 (4.7/1,000) in 1969 to 114/13,111 (8.7/1,000) in 1970; the frequency of cleft lip from 1 in 13,244 in 1969 (0.07/1,000) to 28/13,111 (2.1/1,000) in 1970. Since the 1969 cleft lip frequency is far below that of any well-documented population, the increase in 1970 must be in a large part due to improved documentation.

The Committee decided that to test the question of association or lack of association between herbicides and malformations with adequate accuracy it was essential to collect data specifically for that purpose. An ideal research plan was designed which would allow comparison of heavily sprayed and unsprayed populations, but considerations of safety and practical difficulties involved in defining, locating, and studying appropriate populations in wartime, in a country where a very large proportion of the people had been displaced, led us to give up this plan. Instead we began a pilot study, with careful examination of the records on one hospital unit (the Barsky Unit, Cho-Ray Hospital, Saigon-Cholon) which had treated a very large number of cleft lip and palate patients, and which had fairly comprehensive records, covering a sizeable proportion of the total number of babies born with cleft lip and/or cleft palate in SVN since the unit was established. This study has not yet been completed, mainly because of the time required to compare all information. The results will be reported when available. The analyses we could complete so far provide no evidence of an increase in congenital malformations related to herbicide spraying. It must be pointed out, however, that the circumstances were such that an appreciable increase in the malformation rate in the offspring of sprayed individuals could have remained undetected by our investigation.

(2) The TCDD Problem in South Vietnam

TCDD in Soil and Fish and Shellfish from Southeast Asia

TCDD (see Section II C[4]) occurs as a contaminant of 2,4,5-T; the herbicide most widely used in the Vietnam war. This Section briefly reviews the present status of the TCDD problem in SVN.

When the Committee's field studies were being planned and carried out we were not in the possession of information regarding the extent and distribution of the use of Agent Orange and thus the possible distribution of TCDD in SVN. Nor were there methods available to detect it at the low levels of concentration which might be found after spraying in soils, plants, and animal tissues. Analyses were carried out for the soil samples from the Pran Buri Calibration Grid which had received a total of almost 1000 lb/acre of 2,4,5-T in 1964-65 (see Section V A). The analyses were conducted by the Huntingdon Research Centre, using the method described by Woolson et al. (1973), and the results, compared with data on 2,4,5-T, are shown in Table VII A-3. Three of the six samples contained TCDD. Two of these also contained 2,4,5-T, but the third did not, nor was TCDD detected in the sample with the highest 2,4,5-T content (No. 3). Two samples from a site which was as far as could be ascertained, outside the Calibration Grid perimeter contained neither compound. Assuming firstly that no degradation of the TCDD took place, and secondly that the recovery was 100 percent, the original concentration of the TCDD in the Agent Orange (2,4,5-T ester) sprayed on the Calibration Grid would range from <3 to 50 ppm. The soil of the Calibration Grid was sandy, and therefore favorable for leaching, but the high persistence of TCDD in soils of this type agrees with the results of experimental tests (see Section II C[4]).

At a time when the Committee was reaching the end of its investigations, Baughman and Meselson (1973) developed their new, highly sensitive analytical method for the compound and reported to have found TCDD in fish and shellfish from SVN. Their results are shown in Table VII A-4. The highest concentrations were found in fish samples from the Dong-Nai River above Bien-Hoa. Lesser quantities were found in fish and shellfish samples from the Saigon River north of Saigon, and from the seacoast at the Can-Gio District, in the southeastern end of the Rung Sat Special Zone. All samples were collected in 1970 and analyzed in 1973. The watershed of the Dong-Nai River includes the heavily sprayed War Zone D north and northeast of Saigon. The Saigon River drains parts of War Zone C, to the west of War Zone D. The number of samples studied by Baughman and Meselson (1973) is quite small and no samples were taken from rivers in SVN which did not drain heavily herbicide-sprayed areas, nor from locations elsewhere in Southeast Asia. The only control used was a fish from Cape Cod; no TCDD was detected in this material (limit, 0.000003 ppm). However, the pattern of the TCDD levels found is consistent with origin in Agent Orange. Baughman and Meselson (personal communications) analyzed their samples also for hexachlorodioxin and 1,3,6,8-tetrachlorodioxin which should be present

Table VII A-3

Results of TCDD Analyses in Soil Samples from the

Calibration Grid near Pran Buri

Sample No.	TCDD ppm	TCDD lb/acre	2,4,5-T ppm	2,4,5-T lb/acre
1	<0.0012	<0.003	<0.02	<0.03
2	0.0135	0.042	<0.02	<0.03
3	<0.0012	<0.004	0.61	1.35
4	0.0233	0.060	0.43	0.96
5	<0.0020	<0.006	0.02	0.06
6	0.0052	0.016	0.04	0.09
Controls				
1	<0.0012	<0.003	<0.02	<0.02
2	<0.0012	<0.003	<0.02	<0.02

Only the top portions (ca. 20 cm) of the cores were analyzed for TCDD. The center portion of Core No. 2 contained no detectable TCDD (<0.0012 ppm).

Table VII A-4

TCDD in fish and shellfish from SVN.
(After Baughman and Meselson, 1973)

Collection Site	Fish or Shellfish	Mean TCDD level (ppm wet body weight)
Dong Nai River, north of Bien Hoa	Carp (Cyprinidae)	0.000540
	Catfish (Siluridae)	0.000814
	Catfish (Tachipuridae)	0.000522
Saigon River, north of Saigon	Catfish (Schilbacidae)	0.000070
	River prawn (Palaemonidae)	0.000042
Can Gio District (seacoast)	Croaker (Sciaenidae)	0.000079
	Prawn (Penaeidae)	0.000018

Collections were made in August-September 1970. The entire fish or shellfish was ground and kept frozen until analysis. Values corrected for recovery.

in pentachlorophenol (see Section II C[4]), and tested whether TCDD might arise from 2,4,5-T or 2,4,5-trichlorophenol during the preparation of the fish material for analysis. The results were negative, indicating that pentachlorophenol was not the source of the TCDD found, nor that TCDD was formed during the analytical procedures.

TCDD Content in Agent Orange Used in SVN

The levels of TCDD occurring in Agent Orange varied from less than 0.05 ppm (the detection limit of the analytical method used) up to 47 ppm (analyses carried out for DOD by Dow Chemical Company). These figures are based on determinations in stocks that were returned from SVN (Table VII A-5) and stocks that were procured but never shipped to SVN (Table VII A-6). As far as the Committee could ascertain no records were kept on which brand of the Agent was used on which herbicide missions in SVN and at which time. Thus, only the total arithmetic means can be estimated; for the stocks listed in Tables VII A-5 and VII A-6, these are somewhat less than 2 and 3 ppm, respectively.

A total of about 10,630,000 gallons were shipped to and used in SVN, according to procurement and shipping records. This figure does not, however, agree fully with that of 11,262,000 gallons used on herbicide missions as recorded on the HERBS tape for the period August 1965 to February 1971 (see Section III C). If we use the above arithmetic means and the gallonage of the procurement records, we can calculate that about 220 to 325 lb of TCDD were released over SVN; if we use the HERBS tape gallonage (which does not include pre-August 1965 missions, some helicopter missions, some dumps, and some other although relatively minor uses) the figures become about 235 to 360 lb. However, in view of the limited sample numbers and the uncertainty about use of different stocks, these values are no more than estimates of the order of magnitude.

Future Needs

Baughman and Messelson's (1973) findings caused much concern in SVN and led Japanese authorities to impound frozen shrimp from SVN exported to Japan, resulting in a serious potential setback for a rapidly developing industry of SVN. Thus there is evidence that TCDD persisted, at least about half a year after termination of the military use of Agent Orange, in fish and shellfish of SVN, and longer in soils which had received extremely high amounts of 2,4,5-T. The biological significance of these observations is not known and work on this problem is, therefore, urgently needed. The data of Baughman and Meselson should be confirmed by independent analyses, if possible including a different technique. If they are confirmed, further and expanded research will be urgently needed including a systematic program of sampling in SVN. Even though Baughman and Meselson's data point to Agent Orange as the most likely source of the TCDD found, a search should be made for other potential sources. Another activity appears no less essential and urgent. The finding of a TCDD content in fish of close to 1000 ppt (0.001 ppm) is disturbing. However, while the sensitivity of analytical methods has been greatly improved, permitting the detection of materials which were previously

Table VII A-5

2,3,7,8-Tetrachlorodibenzo-para-dioxin (TCDD) analyses on 200 random samples from Agent Orange stocks presently stored on Johnston Island (returned from SVN).

(Source: DOD; analyses carried out by Dow Chemical Company)

Results are given as ppm by weight. The accuracy of all values is ± 20 percent of the amount reported. Several samples contained significant interferences. For these samples, a maximum value for the amount which could be present is given.

TCDD, ppm	Percent of Samples
< 0.05	12.5
0.05-0.1	21.0
0.11-0.5	35.0
0.51-1.0	8.5
1.1 -2.0	4.0
2.1 -3.0	3.0
3.1 -5.0	5.0
5.1 -7.0	2.5
7.1 -10.0	6.0
10.1 -20.0	1.0
> 20.0[a]	1.5

Arithmetic mean of all samples: 1.91 ppm

[a] Three samples of 22, 33, and 47 ppm.

Table VII A-6

TCDD Analyses on Agent Orange Samples from Different Suppliers Remaining at Gulfport, Miss.

(Source: DOD; analyses carried out by Dow Chemical Company)

Manufacturer	Gallons Procured	Percent of Total Procurement	Dioxin (TCDD) Concentration, ppm[a] Mean	Range
A	2,406,041	18.7	< 0.05	all < 0.05
B	4,022,534	31.1	0.12	0.1-0.2
C	333,685	2.6	0.17	0.1-0.3
D	1,036,475	8.1	0.32	0.3-0.4
E	3,561,040	27.7	7.62	6.9-9.3
F	696,685	5.4	8.62[b] 14.4	8.0-9.7 12.0-17.0
G,H,I	817,288	6.4	-	-
Total	12,873,748	100.0	-	-
Arithmetic mean[c]	-	-	2.99	-

[a] Analysis based on six random samples each.

[b] Two different production lots.

[c] Of all samples for which analyses are available.

suspected to be present in the environment, we remain quite ignorant as to the biological significance of such residues. Although there is now substantial work on the toxicology of TCDD it has been largely limited to mice, rats, and other rodents. It is, therefore, crucial that thorough toxicological and teratological work on TCDD is undertaken, using materials and procedures which may provide as much information applicable to man as possible. It is also no less important that comprehensive work be undertaken on the behavior of TCDD in the ecosystem, particularly, possible bio-concentration in the food chain.

Toward the ends discussed above, a Task Force on Dioxin has been formed and has had several meetings to discuss the latest information from experimental studies, the state of analytical procedures, and the state of the dioxin problem in SVN. The Task Force felt strongly that because there is an indication that dioxin may be present in the food and water of SVN and may present a hazard to the health of the Vietnamese people, studies of the concentration and distribution of dioxin in the SVN environment must be carried out as soon as possible. Discussions are being held with the U.S. Agency for International Development (USAID), Department of State, for support of the studies.

(3) Epidemiological Effects of Ecological Change

Vector-borne diseases, particularly malaria, constitute a major cause of morbidity and mortality in SVN and other parts of Southeast Asia. As of 1960-1961, over 400,000 cases of malaria were reported in SVN (World Health Organization). MacKenzie (1969) states that in Thailand and other areas of Southeast Asia, malaria "has long been recognized as the greatest impediment to community progress." Other vector-borne diseases which constitute a major health problem in this part of the world are filariasis, arboviruses (dengue, viral encephalitis), which like malaria are transmitted by mosquitoes, and plague and various forms of typhus transmitted by arthropod ectoparasites of rodents.

Each insect vector of these infections requires specific enviornmental conditions for breeding and other activities essential to their life cycle. For example, mosquitoes are very precise in selecting exactly the right kind of water in which the larvae of their species are best adapted to develop. Some species deposit their eggs in brackish water, others in flowing, sunlit mountain streams, others in rice paddies, while still others utilize small ground pools of rain water. The Committee considered the possibility that the ecological changes consequent to the application of herbicides could result in new environmental conditions better or less well suited to the breeding and development of vectors and reservoirs of infectious diseases. The constraints of military security, available time, and funds permitted the Committee to investigate this hypothesis in only one affected ecosystem, the mangrove forest. Moreover, because of these constraints and the potential magnitude of the malaria problem, the Committee focused upon this particular disease. Some information on the rodent population in intact and defoliated mangrove forests was also collected.

The results of this study indicate that few, if any, anopheline mosquitoes are present or breed in intact estuarine and coastal mangrove forests. As a consequence, malaria is not present in human communities living within this ecosystem. Destruction of the estuarine mangrove forest by herbicide application did not directly result in ecological conditions suitable for the propagation of anopheline mosquitoes. However, following defoliation, a series of events occurred that is believed to have led to the introduction of anophelines and transmission of malaria. The estuarine mangrove southeast of Saigon, in the Rung Sat Special Zone, became relatively secure after herbicides were applied and subsequent deforestation. Immigrants from the Delta and some of the indigenous population who could no longer pursue woodcutting as a means of livelihood, turned to rice farming. Anopheles sinensis and A. lesteri seem to be breeding prolifically, at least during the rainy season, in the newly created rice fields. Malaria, probably brought in by the immigrants and also possibly by the NLF, is now being transmitted and is endemic in the communities in this region.

There is also some evidence that the rat population has increased following destruction of the mangrove forests.

The results of these studies are summarized in Table VII A-7.

Intact and Defoliated Estuarine Mangrove

The Rung Sat, an estuarine mangrove forest in which approximately 57.3 percent of the area had been sprayed with herbicides (see Section IV C), was selected as a study site. Unfortunately no relatively secure comparable unsprayed, intact estuarine mangrove forest could be found in SVN to serve as a "control" study site. This lack of a control mangrove area constituted a serious impediment to conducting a scientifically valid study. The deficiency was compounded by the fact that the mangrove ecosystem has been almost entirely neglected by medical zoologists and epidemiologists; thus there was very little background information available on the species of mosquitoes/reservoir hosts or the kinds of infections which occur amongst the inhabitants of the mangrove forests of Southeast Asia. It was, therefore, decided to search for a congruent area in Thailand that could serve as a control study site. An appropriate study area was found in Chantaburi, Thailand (see Fig. VII A-1). Visits to the area by Committee members and consultants indicated that the botanical composition in this area was similar to that in the Rung Sat prior to herbicide application. Medical studies in the Thai mangrove carried out with the collaboration of the staff of the Bangkok School of Tropical Medicine, Mahidol University, included collections of adult and larval mosquitoes, estimations of rat populations by trapping, collection of ectoparasites from rats, and a survey of malaria. Botanical work by members of the Faculty of Forestry, Kasetsart University, confirmed the general similarity of the vegetation with that of the Rung Sat.

The field work was carried out in November-December 1972 at the end of the rainy season, a time when a high mosquito population was expected. The work was done first in Thailand and then in SVN.

Table VII A-7

Summary of findings in intact and deforested mangrove ecosystems of South Vietnam and Thailand

Area	Mosquitoes			Malaria	Rodents
	Predominant species composing population	Medical importance	Comment		
Intact estuarine mangrove (Chantaburi, Thailand)	Aedine: Aedes dux	Not known	Breeds mainly in fresh water found in tree holes. Readily bites man.	Not present. No positive blood films in 384 children surveyed. No enlarged spleens detected.	Rattus losea predominant species. Trapping results indicate rat population not very high in dense mangrove forest.
	Aedes taenorhynchoides	Not known	Known breeding places are ground pools. In current survey, found in brackish pools in middle of mangrove swamp. These mosquitoes readily attack man.		
	Aedes long rostris	Not known	Known breeding places are pools in mangrove swamps and in crab holes. Found in brackish pools in mangrove in current survey. Does not attack man readily.		
	Culicine: Culex sitiens	No known disease relationships.	Breeds in brackish water in coastal areas, breeding habitats includes ground water as well as artificial containers such as water collected in boats, barrels, etc.		
	Ficalbia: Ficalbia hybrida	No known medical importance.	Tree hole breeder. Does not readily bite man, most specimens caught in light trap.		

Table VII A-7 (Continued)

Area	Mosquitoes				Rodents
	Predominant species composing population	Medical importance	Comment	Malaria	
Herbicide-deforested estuarine mangrove (Rung Sat, S. Vietnam)	Anopheline: <u>Anopheles sinenses</u>	Vector of malaria in China. Can also transmit Bancroftian filariasis.	This species is normally a zoophilic species but it was found to bite man readily in the Rung Sat and will fly indoors to do so. Suspected larval habitat is in standing water of rice fields. This is its normal breeding habitat.	<u>Present</u>. Six positive cases in 84 children examined (7%). Surveys by USAID (1969) and Vietnamese malariologists indicate mesoendemic malaria to be present in Rung Sat.	No collections made. Farmers complain of high rat population destroying rice.
	<u>Anopheles lesteri paraliae</u>	Unknown	Often appears to be associated with coastal brackish-water conditions.		
	Culicine: <u>Culex sitiens</u>	See above.	Found breeding in brackish water of "salt marsh" and in brackish water collected in boats.		
Intact coastal mangrove (Cholburi, Thailand)	Aedine: <u>Aedes dux</u>	See above.		Not known. Presumably not present.	<u>Rattus rattus</u> only trapped but relatively few in number.
	<u>Aedes taenorhynchoides</u>	See above.			
	Culicine: <u>Culex sitiens</u>	See bove.			
Cut-deforested coastal mangrove (Cholburi, Thailand)	Aedine: <u>Aedes taenorhynchoides</u>	See above.		No people residing as yet in area, but presence of potential vector constitutes a hazard when settlement takes place.	<u>Rattus rattus</u> only collected. Four times as many rats trapped than in adjacent intact mangrove.
	Anopheline: <u>Anopheles subpictus</u>	Malaria vector in some areas of Indonesia, but not in India or rest of S.E. Asia. Has also been found infected with <u>W. bancrofti</u>.	Breeding site found to be exposed salt marshes. Also breeds in ground pools. Man is not a preferred host of this species.		

The main results in the intact estuarine mangrove (the "control" area, Chantaburi, Thailand) were as follows:

(1) The ecology of the intact mangrove forest as exemplified in Chantaburi provided few identifiable suitable breeding habitats for anopheline mosquitoes (Table VII A-7). Presumably these were the conditions in the Vietnamese estuarine mangrove before herbicide spraying. The predominant mosquitoes present in the Chantaburi mangrove forest are members of the Aedine, Ficalbia and Culicine groups. Aedes dux, Ae. taenorhynchoides, and Ficalbia hybrida were found to breed mainly in tree holes and Culex sitiens in brackish ground pools. Ficalbia, because of its reluctance to bite man, is of no potential medical importance. The aedine and culicine mosquitoes readily fed on humans. Their role in transmitting arbovirus infections is not considered important, although little is known regarding their role as vectors.

(2) Malaria does not appear to be present in these mangrove communities; there were no positive blood films or enlarged spleens in any of the 384 school children examined. The absence of malaria transmission is notable since the foothills bordering Cambodia about 10 miles from the "control" mangrove study area is one of the "hottest" malaria areas in Thailand.

(3) Trapping results in the Chantaburi mangrove indicate that rodent populations are not high in intact estuarine and coastal mangrove forests. The predominant species in the estuarine mangrove was Rattus losea. Little is known regarding the role of this species as a reservoir of disease but very few ectoparasite vectors, such as the chigger mite (transmitter of scrub typhus), were found on the trapped animals.

In the defoliated estuarine mangrove in the Rung Sat, the investigation was confined, because of security conditions, to a single study site, the hamlet of Tran-Hung-Dao (see Figs. VII A-2 and A-3). Although the area was relatively secure, collections could not be made from some potential mosquito larva breeding sites because of the possible presence of NLF forces; nor could light-trap collections outside the village be made because of the possibility of their being booby trapped during the night. It was possible, however, to make a collection of mosquitoes biting human bait and to make a limited blood survey of 84 school children for malaria.

Two follow-up visits were made to this site by the medical anthropologist Committee member, who obtained information on the history of the hamlet, farming practices before and after defoliation (see Fig. VII A-4), and other data that bear on ecologically related factors influencing the kind of disease vectors and reservoirs in the area (see Section VII C).

The following results were obtained:

(1) The vast majority of the mosquitoes obtained by night-biting collection from human bait and light traps were Anopheles sinensis and the related A. lesteri. These mosquitoes readily flew indoors and avidly

Fig. VII A-1. Estuarine mangrove forest near Khlung, Chantaburi Province, Thailand. Photo taken August 1972 by Dr. Peter Kunstadter.

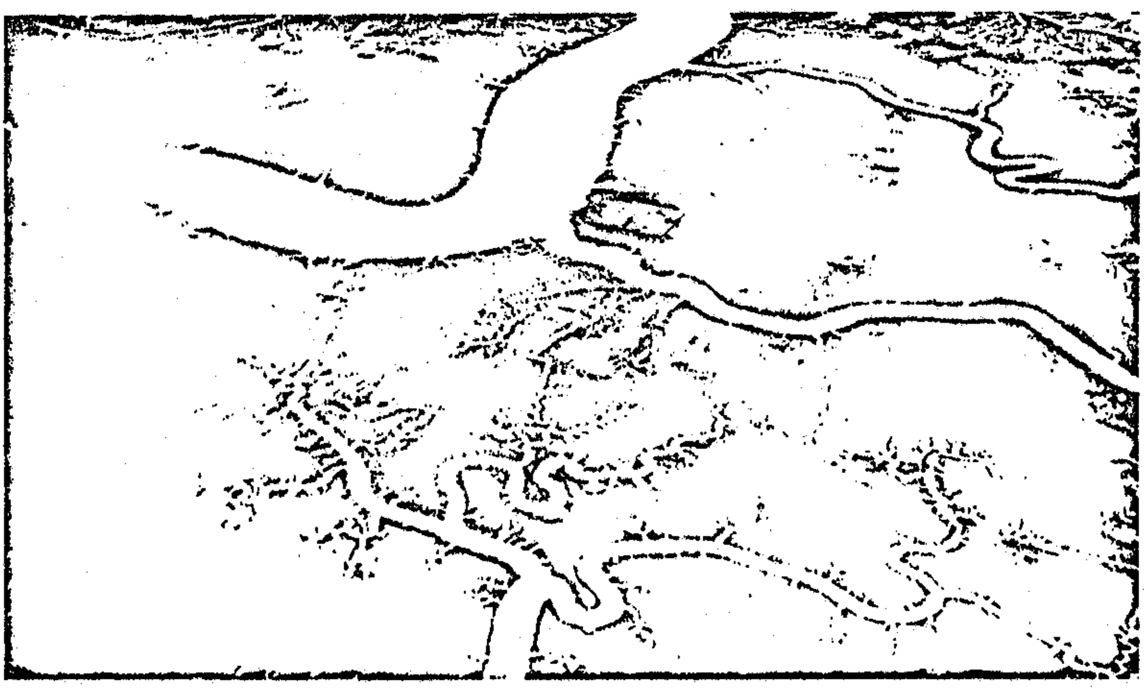


Fig. VII A-2. Tran-Hung-Dao Hamlet in defoliated area of Rung Sat showing rice fields. Photo taken December 20, 1972 by Dr. Peter Kunstadter.

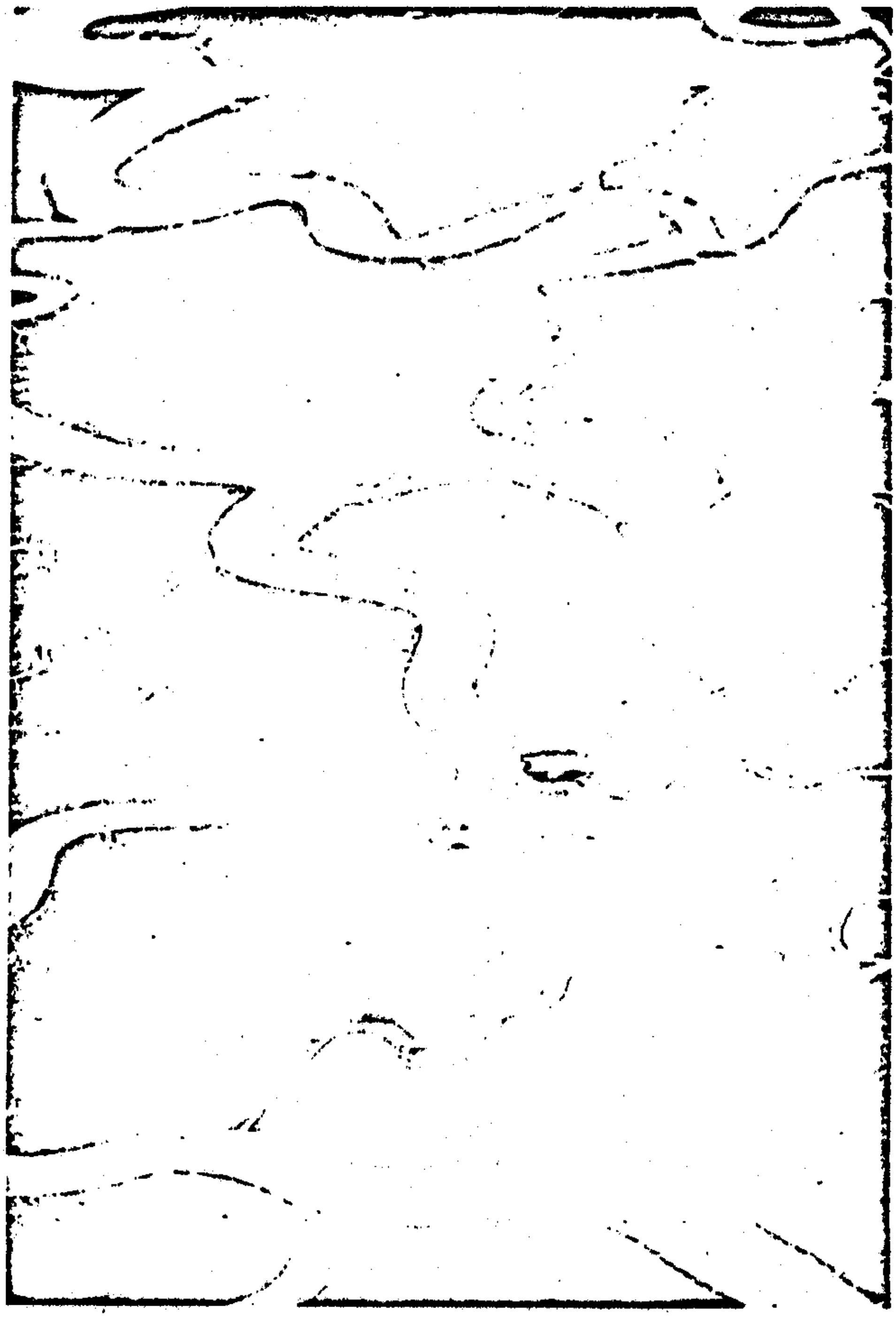


Fig. VII A-3. Defoliated area of Rung Sat showing Tran-Hung-Dao Hamlet on main shipping channel. Photo looking south taken January 6, 1970.

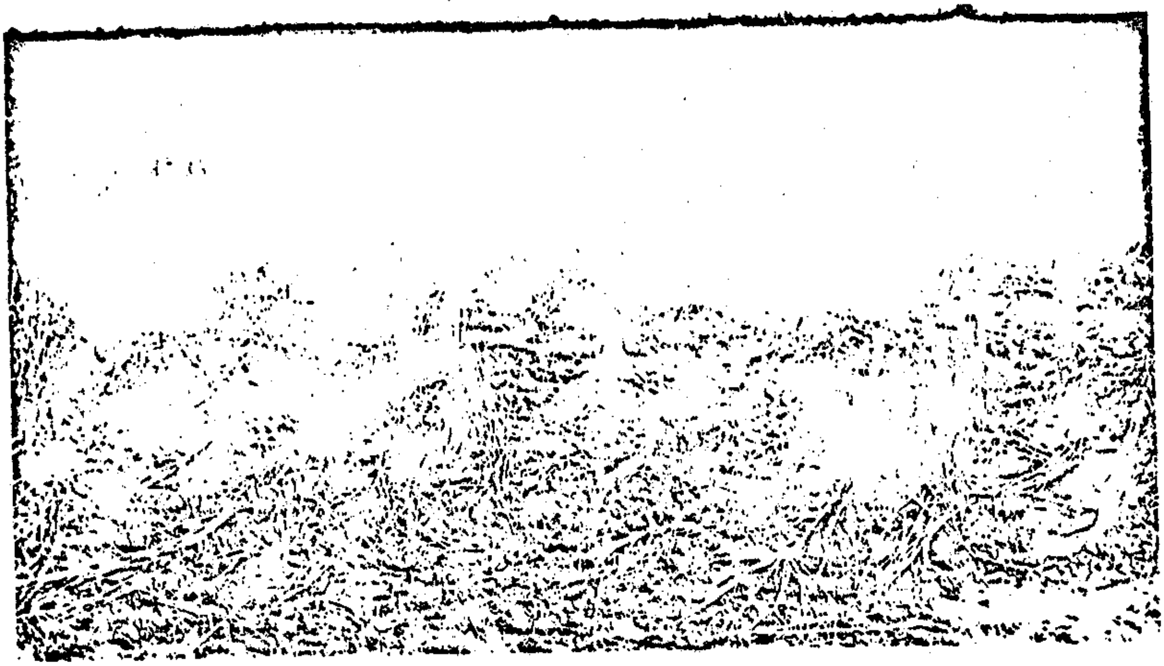


Fig. VII A-4. Harvested rice fields near Tran-Hung-Dao Hamlet. Photo taken January 2, 1973 by Dr. Peter Kunstadter.

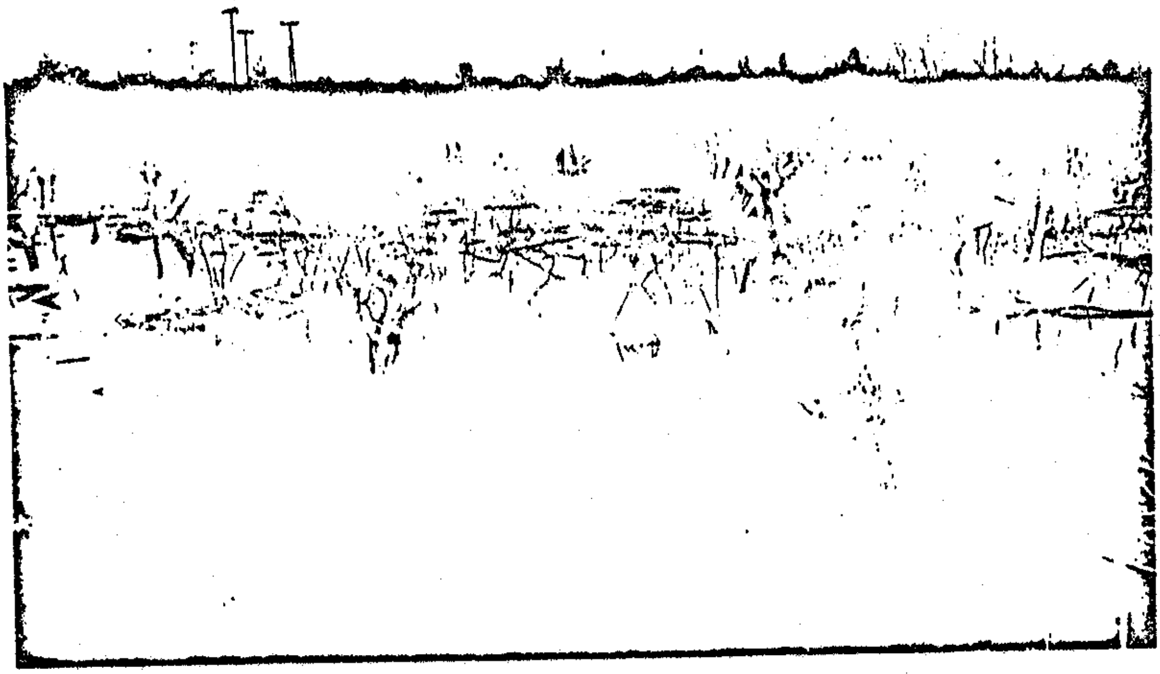


Fig. VII A-5. Hand-cleared coastal mangrove forest near Cholburi, Thailand. Photo taken August 1972 by Dr. Peter Kunstadter.

sought a human blood meal. Examination of many pools of water in the defoliated area adjacent to the hamlet failed to reveal the larval breeding sites of these mosquitoes. Since it is known from other areas of Southeast Asia where these Anophelines occur that they breed mainly in rice paddies, it is believed that in our study area the larval breeding site is in the water associated with the newly-introduced rice cultivation. However, it was not possible to confirm this because security conditions prevented us from making collections in the rice paddies which were situated about a quarter of a mile from the hamlet.

With the exception of *Culex sitiens* none of the mosquitoes found in the intact, control mangrove area were found in the deforested study site.[a]

(2) A blood survey carried out in the study community gave a malaria point-prevalence rate of 7 percent amongst the 84 randomly selected school children examined. There was no opportunity to carry out fever detection or a spleen rate survey but it is believed that these methods would have indicated an even higher malaria prevalence.

Information provided by the Malaria Section of USAID/Saigon showed that although malaria in the Delta and Saigon-Gia Dinh areas is ordinarily of very low prevalence there have been outbreaks of malaria in the Rung Sat since, at least, 1969 of sufficient severity to require the attention of the Malaria Service of the RVN Ministry of Health. This was the year people living in Tran Hung Dao reported that they began farming in the vicinity of the hamlet. It appeared to us, from aerial observations and study of aerial photographs, that our study site was typical of the Rung Sat. However, further study would be required to ascertain that the factors governing transmission of malaria in this site are operative in other areas of the Rung Sat.

Malaria was probably introduced into the Rung Sat by migrant "carriers" coming from or through endemic areas, including NLF and North Vietnamese soldiers. Military medical intelligence reports indicate that malaria has been a considerable problem in both of these forces.

In all probability malaria transmission occurs only during the rainy season and ceases when the rice fields, the breeding habitat of the Anopheline vector, dry out in the dry season. A survey for malaria vectors in the dry season could not be carried out but members of the community studied informed us that very few mosquitoes were present during this period.

(3) It was not possible to collect rats in the Rung Sat. Local farmers reported that the rat population has increased so enormously in

---

[a] Excluded from this discussion is *Aedes aegypti*, an ubiquitous species breeding in fresh water containers. Its presence is obviously not affected by the ecological conditions under consideration.

recent years that rats are destroying half the rice crop. They attribute the increase in rat population to the grass and debris, suitable breeding habitats, which have replaced the mangrove forests. We have been unable to collect epidemiological data regarding the presence of reservoir-associated diseases (plague, leptospirosis, typhus) in the Rung Sat.

Intact and Deforested Coastal Mangrove (Cholburi, Thailand)

It was not possible to investigate the impact of herbicide spraying on ecology-epidemiology in a coastal mangrove ecosystem such as that present in the Delta region of SVN. However, a typical coastal mangrove forest was identified in Thailand, near Cholburi town (see Fig. VII A-5). An extensive part of this forest had been deforested by cutting to make way for a housing project although no construction had yet been started. This offered an opportunity for studying epidemiological-ecological effects of removal of mangrove vegetation by means other than herbicides.

The study carried out in the coastal mangrove of Cholburi provides another indication that deforestation of mangrove can lead to anophelism. In the intact forest the predominant species of mosquitoes were similar to that of the Chantaburi estuarine mangrove (*Aedes dux*, *Ae. taenorhynchoides*, and *Culex sitiens*). Very few *Anopheles* were caught and these were considered to be "strays" breeding in adjacent rice fields and deforested areas. *Anopheles* breeding sites were not found in the intact mangrove forest.

In the adjoining cleared area the mosquito population was distinctly different. Here the predominant species were *Anopheles subpictus malayensis* and *Anopheles subpictus subpictus*. These were found breeding, along with *Culex sitiens*, in the exposed salt marshes and ground pools that formed after deforestation. No settlement of this area has yet taken place nor is the capacity of the particular local strains of *Anopheles subpictus* as a vector known. The species is a vector of malaria in Indonesia and India. The potential menace of malaria transmission when housing and settlement are developed must be seriously considered.

Trapping results suggest that the rodent population, predominately *R. rattus* (a known potential reservoir of plague and other infectious diseases), was four times higher in the deforested coastal mangrove than in the adjoining intact mangrove forest of Cholburi.

(4) Discussion

Although the limitations under which our studies, particularly those in SVN, were conducted did not allow them to meet all exacting demands of scientific inquiry and were relatively narrow in scope, the data indicate the possibility that ecological alterations caused by defoliation may result, directly or indirectly, in a new set of environmental conditions highly suitable for breeding and propagation of insect vectors of disease when these are introduced. We have focused upon malaria and its vectors not only because it was the infection most readily accessible for study but also because malaria has a tragically long history in Southeast Asia of debilitating large population groups. The potential danger of the situation is further compounded by the fact that in recent years strains of malignant tertian malaria (*Plasmodium falciparus*) resistant to the mainstay chemotherapeutic antimalaria agents have emerged and become widespread in that region. We have not investigated other vector-borne diseases, but there is a suggestion that rats, potential reservoirs of plague, typhus and leptospirosis, have proliferated in deforested mangrove areas.

REFERENCES

Baughman, Robert and Matthew Meselson, 1973. An analytical method for detecting TCDD (Dioxin): Levels of TCDD in samples from Vietnam. Environmental Health Perspectives, Experimental Issue No. 5, 27-36.

Baughman, Robert and Matthew Meselson, personal communication.

Corey, M.D., J.C. Andrews, M.J. McLeod, J.R. Maclean and W.E. Wilby, 1970. Chromosome studies on patients (in vivo) and cells (in vitro) treated with lysergic acid diethymlamide. New England J. Med. 282:939-943.

Cutting, R.T., T.H. Phuoc, J.M. Ballo, M.W. Benenson, and C.H. Evans, 1970. Congenital malformations, hydatidiform moles and stillbirths in the Republic of Vietnam, 1960-1969. U.S. Government Printing Office, Washington, D.C.

Emanuel, I., H. Shih-Wen, L.T. Gutman, F.-C. Yu, and C.-C. Lin, 1972. The incidence of congenital malformations in a Chinese population: The Taipei collaborative study. Teratology 5(2).

Kilian, D.J., 1973. (Industrial Medicine, Dow Chemical U.S.A., Texas Division, unpublished).

Le-Anh (Madame) (nee Nguyen-thi-Kim-Hoan), 1970. Les malformations congenitales au Viet-Nam. M.D. Thesis, Universite de Saigon, Faculte de Medecine, Saigon, Vietnam.

MacKenzie, D.J.M., 1969. Notes on problems facing malaria eradication programmes in tropical zones, with special reference to Thailand. WHO/Mal/69.698 (unpublished document).

Meselson, M.S., A.H. Westing, and J.D. Constable, 1971. Background material relevant to presentations at the 1970 Annual Meeting of the AAAS. American Association for the Advancement of Science, Herbicide Assessment Commission. U.S. Congressional Record, 92nd Congress, 2nd Session, 118(32):S 3227-3233, March 3, 1972.

______, 1972. Preliminary report of Herbicide Assessment Commission of the American Association for the Advancement of Science. U.S. Congressional Record, 92nd Congress, 2nd Session, 118(32):S 3226-3227, March 3, 1972.

Ton That Tung, Trinh Kim Anh, Bach Quoc Tuyon, Dao Xuan Tra, and Nguyen Xuan Huyan, 1971. Clinical effects on the civilian population as a result of the massive and continuous use of defoliants. (Introductory study). Etudes Vietnamiennes, pp. 57-87. Translated by: Phil Fisher, 71-12-3.

Woolson, E.A., W.L. Reichel, A.L. Young, and P.D.J. Ensor, 1973. Dioxin residues in Lakeland sand and bald eagle samples. Advances in Chemistry Series, No. 120, Chapter 12, Chloro-dioxins: Origins and Fate, pp. 112-118.

B. Socioeconomic and Psychological Effects

This Chapter of the Section on effects of herbicide operations on humans in SVN is composed of three units. A question addressed in each is the economic impact of herbicides in human communities. The sources of data used are photography, published records, and interviews with people. The first unit takes a broad look at this issue by analysis of aerial photography, and presents data from a sample of sites covering different land-use types scattered throughout SVN. The next two units are ground studies, the first of which concerns the lowlands (Mekong Delta and Terrace Regions) and the second the highland parts of the country. Some of the photo-interpretation sites complement the studies where people were interviewed and documents consulted.

In addition to the economic question, the last two units also take up a number of topics about which Vietnamese people were asked to tell how they perceived the effects of the herbicide operations. These topics concern, for example, human health, injury to plants and animals, compensation, and attitudes about the use of herbicides as a tool of war.

(1) Herbicide Effects on Settlement Types as Shown by Aerial Photography

Aerial photographs have been taken in large numbers for many years over the area of SVN. Interpretation of these photographs can provide: (1) estimates of population size (through counts of inhabited dwellings), (2) information on the kind and extent of agricultural and other economic activities (by examining fields in or out of cultivation), and (3) information on the presence or absence of effects of herbicide operations (by noting spray swaths across damaged or destroyed vegetation). By comparing photographs of the same settlement and its adjacent cultivated fields taken over a period of years it is possible to describe the changes in population size, in settlement forms, and in agricultural activities, and to assess the effects of herbicide missions and of other war-related activities: bombing--from craters present; spraying--from damage or destruction to cultivated tree, bush, and field crops; and ground combat--from tracks of vehicles, from the shelling and burning of houses leaving only house walls or foundation platforms remaining, from the cutting of trees and bushes, and from the presence of fortifications, gun placements, and trenches.

(a) Sites Selected and Methods Used

Using aerial photographs, a study was made of 18 areas representing six different types of settlements and land use. The purpose of the study was to determine the changes in population, in settlement form, and in land use as a result of exposure to herbicides. The study areas were selected on the basis of a map survey comparing the general locations of sprayed areas with settlements and information on the socioeconomic conditions of the Vietnamese and aboriginal Highland peoples (Montagnards) of SVN.[a] Originally, 25 areas were selected, but seven of them had to be eliminated because evidence from

[a]One exception to this mode of selection was Study Area 10 (see below).

the aerial photos indicated that other war-related activities (bombing, ground action) had resulted in depopulation of the areas before herbicide operations over the areas were begun. The locations of the 18 study areas interpreted in detail are shown on Fig. VII B-1 and listed in Table VII B-1. In the table, those areas that coordinate with studies reported elsewhere in this report are identified by cross-references. These 18 areas were not, however, the only places containing settlements exposed to spraying; many others could have been selected, the number 18 being determined by the limitations of resources and time. Each study area had to be covered by aerial photography at a scale adequate for interpretation taken at times before, during, and after herbicide spraying. The results of the aerial photo interpretation indicate general patterns or consequences of the application of herbicides on settlements, land use, and other economic activities for the areas studied, but because of the sampling method the findings cannot be used to obtain (or extrapolate) a nationwide quantitative estimate of these effects.

Using 1:50,000 scale topographic maps obtained from DOD, base maps were constructed of each of the selected study areas (see sample, Fig. VII B-2). On the maps all settlements are represented as they were in the immediate pre-spray period (usually 1965). This latter information was verified by interpretation of aerial photos taken prior to the beginning of spraying. On an overlay to this pre-spray base map for each study area, the location, dates, scales, and print numbers of all vertical aerial photographs were plotted from information supplied by the U. S. Army Engineer Topographic Laboratories. In order to select photographs of those parts of the study areas that had been sprayed with herbicides, another overlay was constructed on which was plotted the locations of the center-lines, dates, agents, and quantities of all herbicide missions as recorded on the HERBS tape printout. This printout included only herbicide missions from August 1965 to February 1971 but covered the majority of the herbicide operations (compare Section III A-3).

From a correlation of these two overlays (aerial photos and herbicide missions), orders were placed for the aerial photos needed (selected for largest scales available, for maximum extent of areal coverage, and to provide a time sequence of different seasons over as many years as possible). Each run, or sequence, of photographs had sufficient overlap or sidelap to allow stereoscopic (three-dimensional) interpretation. Fig. VII B-3 is an example of a base map of a study area overprinted with the aerial photo runs selected for use in interpretation of that study area, and Fig. VII B-4 an example of a base map for a study area overprinted with all of the herbicide spray missions. Figs. IV C-6 and IV C-7 in the section on the mangroves show the herbicide missions in the study area of Fig. VII B-3.

The aerial photography available for this study was not always ideally suited for the purpose. Only unclassified black-and-white vertical photos were available for the period prior to October 1972. Of the 7,179 black-and-white photographs received, 30 percent were at a scale of 1:30,000 or smaller, useful for mapping general features of the landscape, but of limited value for interpretation; only 32.5 percent were at a large enough

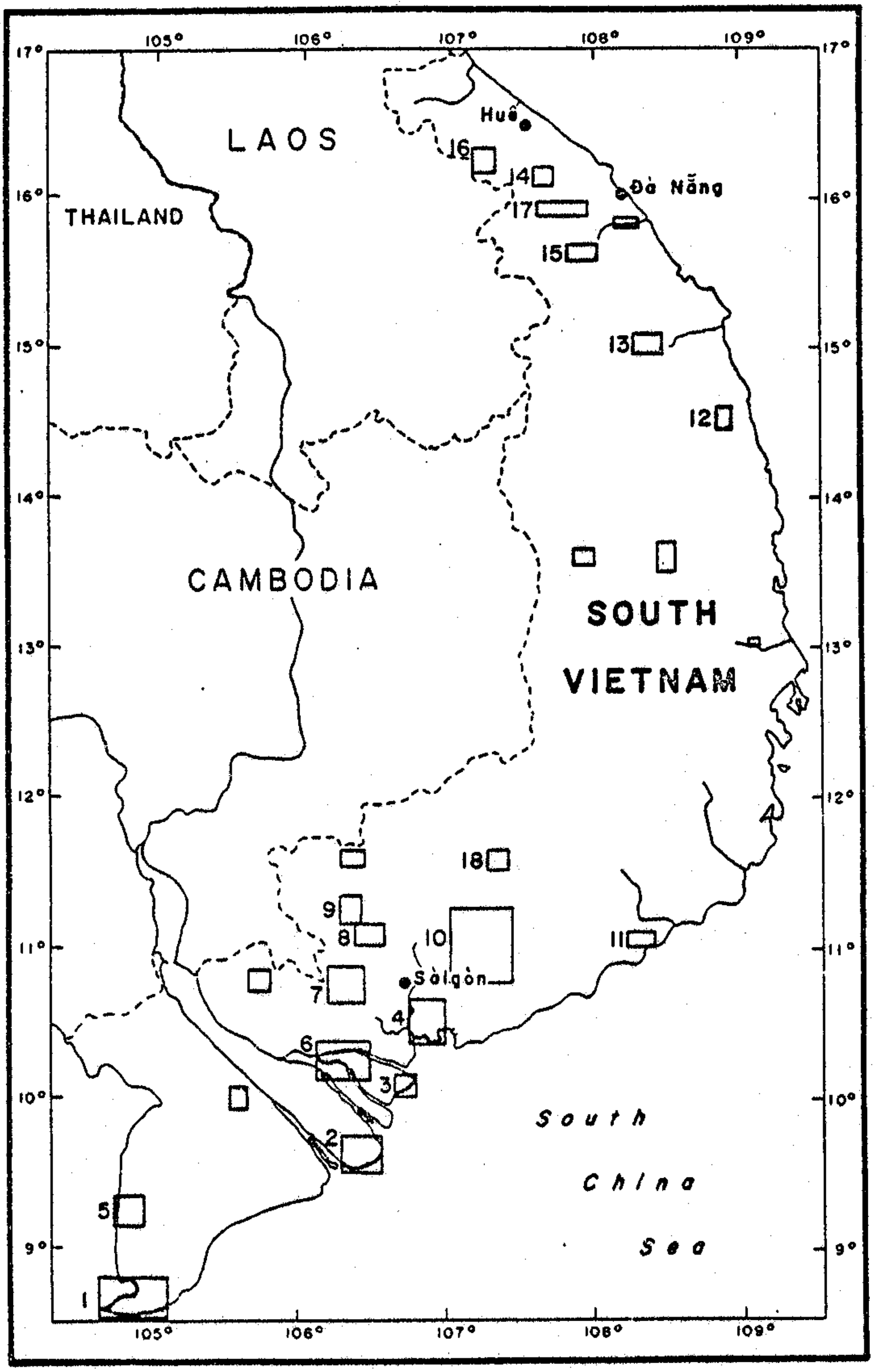


Fig. VII B-1. Location of the 25 areas selected for air photo interpretation study of the human aspects of the use of herbicides in South Vietnam. The seven unnumberered areas are those where air photo interpretation showed that the population had left the area prior to the beginning of herbicide operations. The seven areas were studied in detail, but the results are not included in this report.

Table VII B-1

The 18 Study Areas Subjected to Detailed Interpretation

of Aerial Photographs

Mangrove Settlements (wood-cutters, charcoal makers, fisher folk)

1. Tip of Ca-Mau Peninsula, An-Xuyen Province
2. Mouth of the Mekong Area, Vinh-Binh Province
3. Mouth of the Mekong Area, Kien-Hoa Province
4. Rung Sat Special Zone, Gia-Dinh and Bien-Hoa Provinces (see Sections IV C, VII A[3], VII B[1] and VII C)[a]

Delta Canal-Bank Settlements (irrigated rice--primarily commercial)

5. Coastal Area West of Quan-Long, An-Xuyen Province
6. Truc-Giang (Ben-Tre) Area, Kien-Hoa Province (see Section VII B-2)
7. Area North of Tan-An in Hau-Nghia, Long-An, and Kien-Tuong Provinces

Plantation Settlements (commercial crops for export)

8. Ben-Cat Area, Binh-Duong and Hau-Nghia Provinces (see Section VII B-2)
9. Tri-Tam Area, Tay-Ninh and Binh-Duong Provinces
10. Xuan-Loc Area, Long-Khanh Province (see Section VII B-2)

Lowland Valley Settlements (near coastal plain)

11. Coastal Hills, Binh-Thuan Province
12. An-Lao Area, Binh-Dinh Province
13. Hill Area West of Quang-Ngai City, Quang-Ngai Province
14. Lowland Valley, South of Hue, Thua-Thien Province

Upland Valley Settlements (irrigated rice--primarily subsistence)

15. Valley between Cai and Thu-Bon Rivers, Quang-Nam and Quang-Tin Provinces

Swidden Settlements (upland dry rice and other subsistence)

16. Central A-Shau Valley, Thua-Thien Province
17. Upland Valley, West of Da-Nang, Northern Quang-Nam Province
18. Headwaters Area of Dong-Nai River, Phuoc-Long and Long-Khanh Provinces

[a] The references indicate other sections of the Report containing results obtained at this study site.

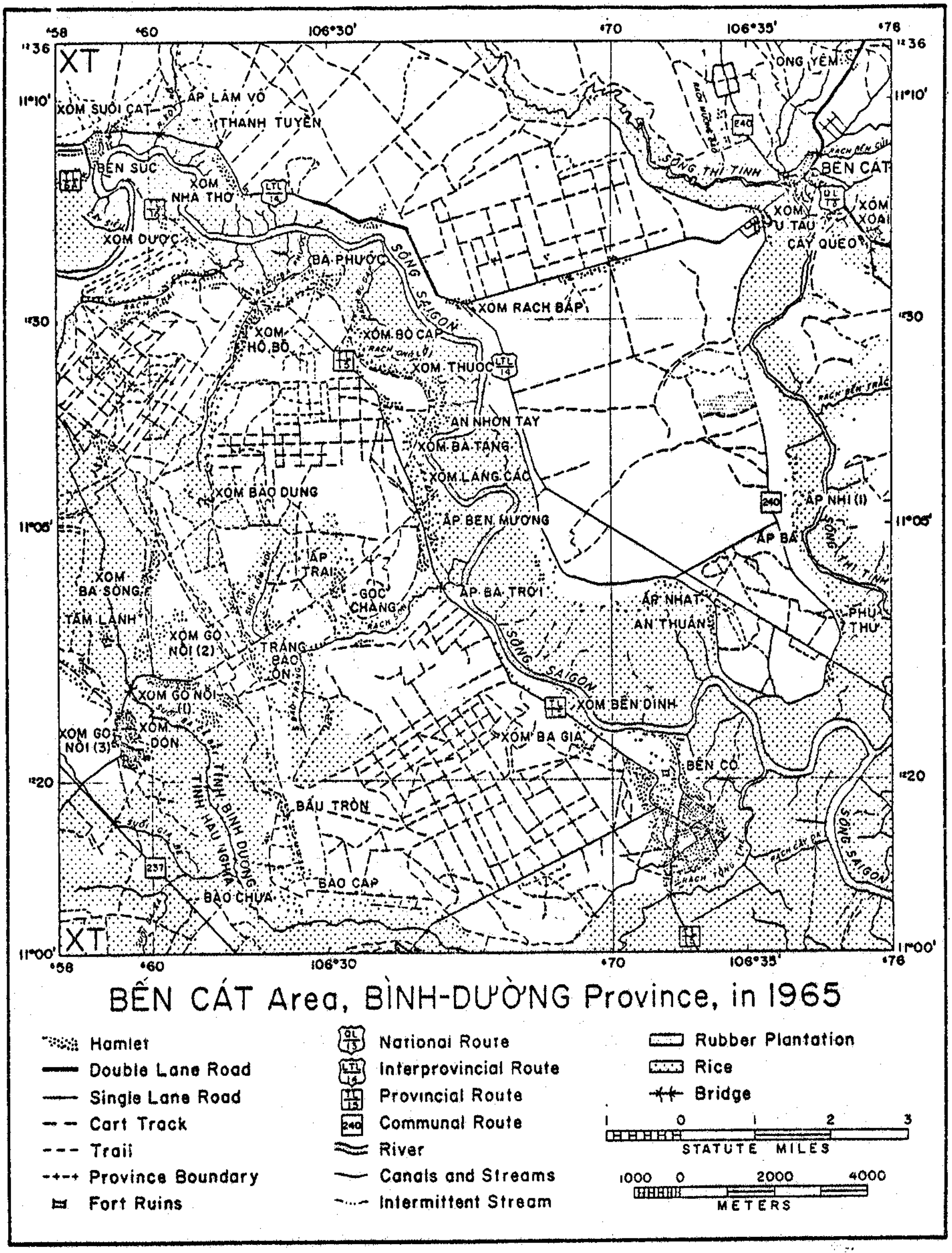


Fig. VII B-2. Sample of a Base Map for a Study Area, showing settlements in 1965, prior to reported herbicide operations. Here shown for Study Area 8, the Ben-Cat Area, Binh-Duong Province. The settlements in the upper left include the hamlets evacuated by the refugees who were resettled in the village of Binh-Hoa, north of Saigon (see Section VII B[2]).

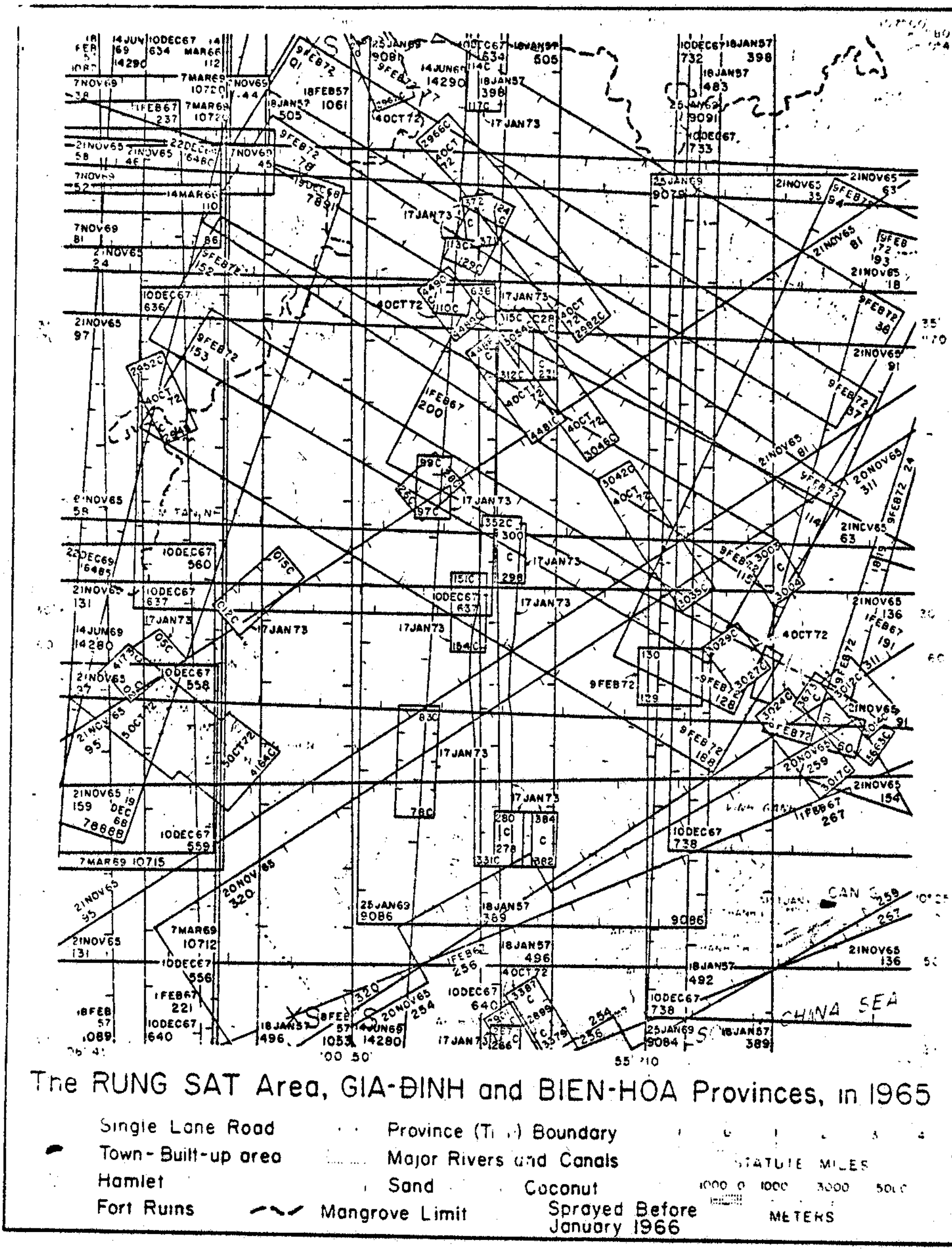


Fig. VII B-3. Sample of a Map of Aerial Photo Runs reported for a Study Area. Here shown for Study Area 4, the Rung Sat Special Zone. Aerial photography runs are identified by date taken, and first and last print numbers, placed within the lines outlining their location. Color transparencies are marked by the letter C.

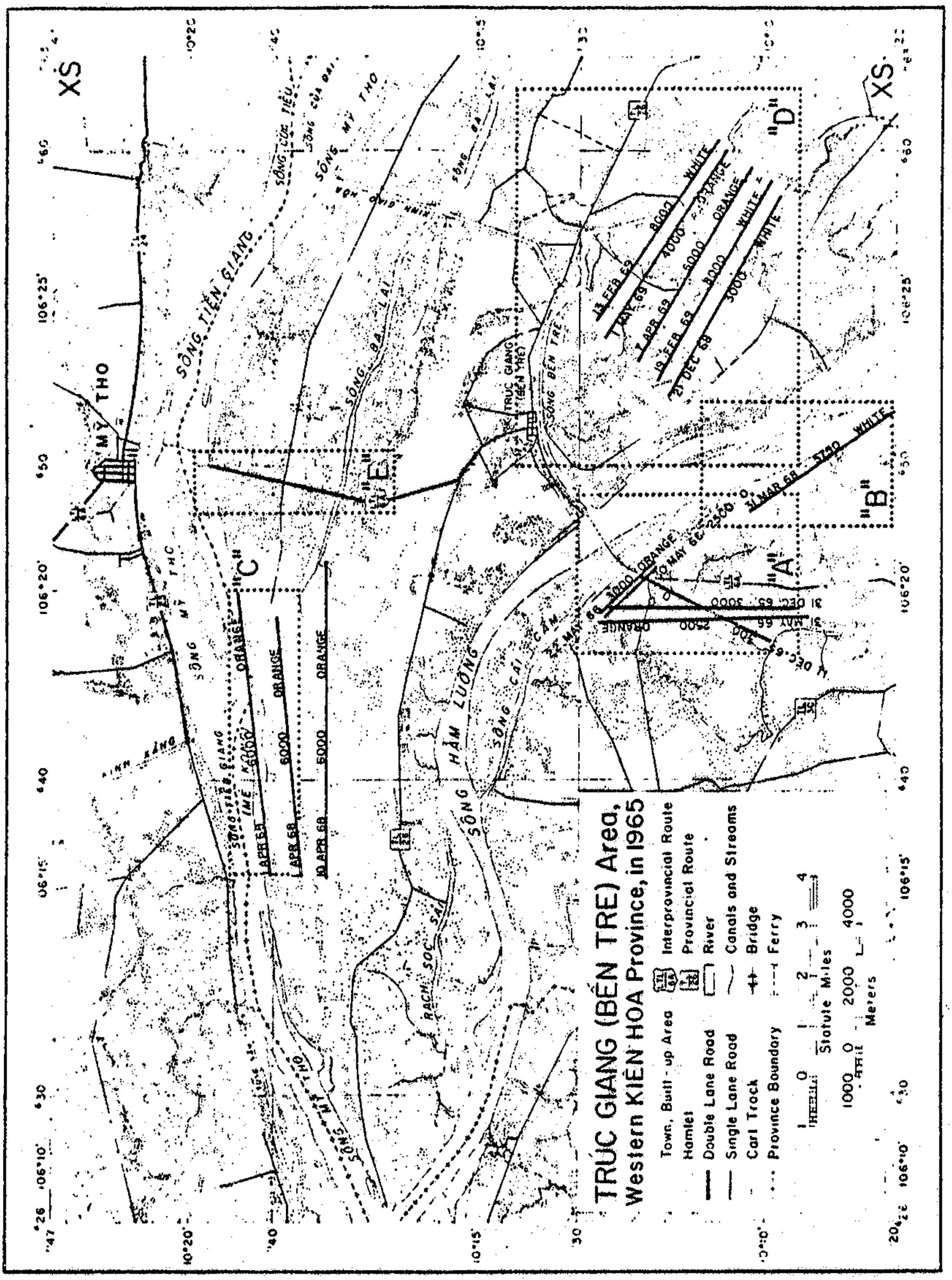


Fig. VII B-4. Sample of a Map of Herbicide Missions reported on the HERBS computer tape printout for the Provinces relevant to a particular Study Area. Here shown for Study Area 6, the Truc-Giang (Ben-Tre) Area, western Kien-Hoa Province. Strips are <u>centerlines</u> of reported herbicide missions (identified by date flown, number of gallons, and agent sprayed), and are <u>not</u> spray swaths with widths drawn to scale appropriate to the number of aircraft flying. The sub-areas "A"-"E" were investigated in detail. Fig. VII B-5 shows detail of sub-area "C".

scale (1:10,000 to 1:4,000) for easy interpretation of relevant features, (footpaths, animal pens, gardens, etc.). Color transparencies numbering 846 were taken in October 1972 and January 1973, well after the end of the period of spraying. All of these were at an appropriate scale and were useful in assessing land-use recovery. They provided very limited coverage, however, of only five study areas. Oblique photos and special emulsion or filter combinations (e.g., color infra-red) that would have been useful for interpretation of damage to vegetation were not taken or not released by DOD.

Population estimates were made by counting the number of occupied houses and multiplying by 7 as the average number of people per house.[a] Evidence of use, such as open trails, neatly arranged houseyards and gardens, crops growing in adjacent fields, were interpreted as indicating that houses were occupied. Partially or wholly destroyed or abandoned settlements were marked by abandoned houses, vegetation growing over paths and cart tracks, damaged or unrepaired houses, overgrown or untended fields and gardens, and dead or damaged vegetation (especially fruit trees).

(b) Sample of Findings from Selected Study Areas

The aerial photographs provided the evidence; their interpretation was conducted as objectively as possible. Each of the 18 study areas was unique in its population distribution, settlement patterns, and kinds and proportion of crops grown. The several illustrations which follow are representative of the findings about the effects of herbicide spraying.

Crop Damage and Destruction. A summary of the intention of the herbicide missions for the study areas is presented on Table VII B-2. Of the total of 1,659 reported herbicide missions, 82.8 percent were for defoliation, and only 10.6 percent for crop destruction and 6.6 percent for other military purposes. Agent Orange was used for 64.8 percent of all missions. Defoliation using Orange was the predominant purpose and agent in 14 of the 18 study areas; the exceptions were Study Areas 8 (Orange used for other purposes), 9 (defoliation using White), 12 (crop destruction using Orange), and 13 (crop destruction using Blue). Except for Study Areas 12 and 13, most damage or destruction of agricultural field and tree crops resulted from missions designated as defoliation rather than as crop destruction. Except for Study Area 13, more crop destruction occurred from the use of Agent Orange than by either Blue or White.

By virtue of its ubiquity in SVN, rice was the most important and most commonly sprayed crop. The damage or destruction of an irrigated rice

---

[a]The Demographic Survey of 14 Cities, 1969-1970 (Dieu-tra dan-so tai 14 thanh pho trong nam 1969-1970), published in Saigon by the National Institute of Statistics on December 2, 1971, gives a total estimated population for 14 cities as 1,536,170 living in 220,970 households, for an average household size of 6.95. Rural households usually are larger than urban ones.

Table VII B-2

Summary of Reported Herbicide Missions for the 18 Study Areas

by Intended Purpose and Agent Used

Study Area Number	Size (sq. mi.)	Reported Number Herbicide Missions	Intended Purpose and Agent								
			Defoliation			Crop Destruction			Other		
			Orange	White	Blue	Orange	White	Blue	Orange	White	Blue
Mangrove											
1	360	76	54	19	-	1	1	-	-	1	-
2	272	51	40	3	2	-	-	-	4	2	-
3	70	34	29	5	-	-	-	-	-	-	-
4	360	299	188	93	17	-	1	-	-	-	-
Delta											
5	196	43	23	17	3	-	-	-	-	-	-
6	375	13	9	4	-	-	-	-	-	-	-
7	308	64	34	19	3	2	-	-	6	-	-
Plantation											
8	139	97	14	22	2	3	1	4	42	1	8
9	196	56	19	22	1	2	2	3	7	-	-
10	1,147	313	165	127	9	8	-	-	1	1	2
Lowland Valley											
11	99	37	16	12	-	7	-	-	2	-	-
12	56	71	21	2	-	24	18	-	-	-	6
13	140	37	16	-	-	3	1	17	-	-	-
14	92	94	45	4	2	12	-	30	-	-	1
Upland Valley											
15	125	31	24	1	1	3	-	2	-	-	-
Swidden											
16	127	121	63	9	10	13	-	1	24	1	-
17	132	77	55	14	-	4	3	1	-	-	-
18	98	145	84	51	1	8	-	1	-	-	-
TOTALS	4,292	1,659	899	424	51	90	27	59	86	6	17
			Defoliation - 1,374			Crop - 176			Other - 109		

Total Missions Using:
Agent Orange - 1075 (64.8%)
Agent White - 457 (27.5%)
Agent Blue - 127 (7.7%)

crop from spraying was ordinarily limited to a single season, unless the spray was repeated in the following season or the population abandoned the area. Destruction of crops and fruit trees in marginally-subsistence agricultural areas must have caused great economic hardships to the local inhabitants. This would have been especially true in the upland irrigated and swidden areas (Study Areas 15-18), particularly among the Montagnards who lacked economic alternatives. Further discussion of herbicide effects as perceived by Montagnards is contained in Section VII B(3) of this report.

The most important and persistent effects of herbicides on commercial crops observed in the aerial photographs were in the coconut groves of Kien-Hoa Province (Study Area 6), the major coconut-producing region of SVN, and formerly an important source of coconuts for export. Fig. VII B-5 provides an illustration of this evidence. Further discussion of the effects on coconut groves as seen from the ground is included in Section VII B(2).

Settlements Subjected to Spraying. For 17 of the 18 study areas (the exception being Study Area 10) there is plentiful evidence from the aerial photographs that inhabited isolated farmsteads, hamlets, and clustered settlements of villages and small towns were directly and repeatedly subjected to aerial spraying by all three agents (Orange, White, Blue). Table VII B-3 summarizes the findings, comparing the location of each settlement with the plotted location of the centerline of each herbicide mission reported on the printout from the HERBS tape. The high percentage of settlements sprayed evident in the table is in keeping with the fact that the study areas were selected for that criterion. It is to be noted, however, that of the 708 settlements exposed, 611 were sprayed more than once and 405 four or more times. Study Area 10, which is the exception, is shown in Fig. VII B-6, and on-the-ground studies conducted in a settlement in this area are described in Sections VII A(3) and VII C. The area is unique in this series in that it was not selected for the congruence of herbicide missions over human settlements but rather as an area where wind drift was believed to have covered wide distances.[a]

---

[a]Damage by herbicide may be from drift as well as from a herbicide mission directly overhead. The count in Table VII B-3 includes all herbicide missions, the centerline of which passed one (1) kilometer from the center of a settlement. The HERBS locations were used because the air photo coverage was not frequent enough to verify the existence of each reported, or actual, herbicide mission. Further, swaths of spray damage overlap one another on the photographs and cannot be distinguished as having been made by several planes on one day, or by one plane on several different days. Finally, Vietnamese settlements are not always clustered; many are linear--along river or canal banks and roads (the units counted were hamlets or the centers of a group of dispersed farmsteads; in the upland valley and swidden areas the units are clusters of several newly-made forest clearings).

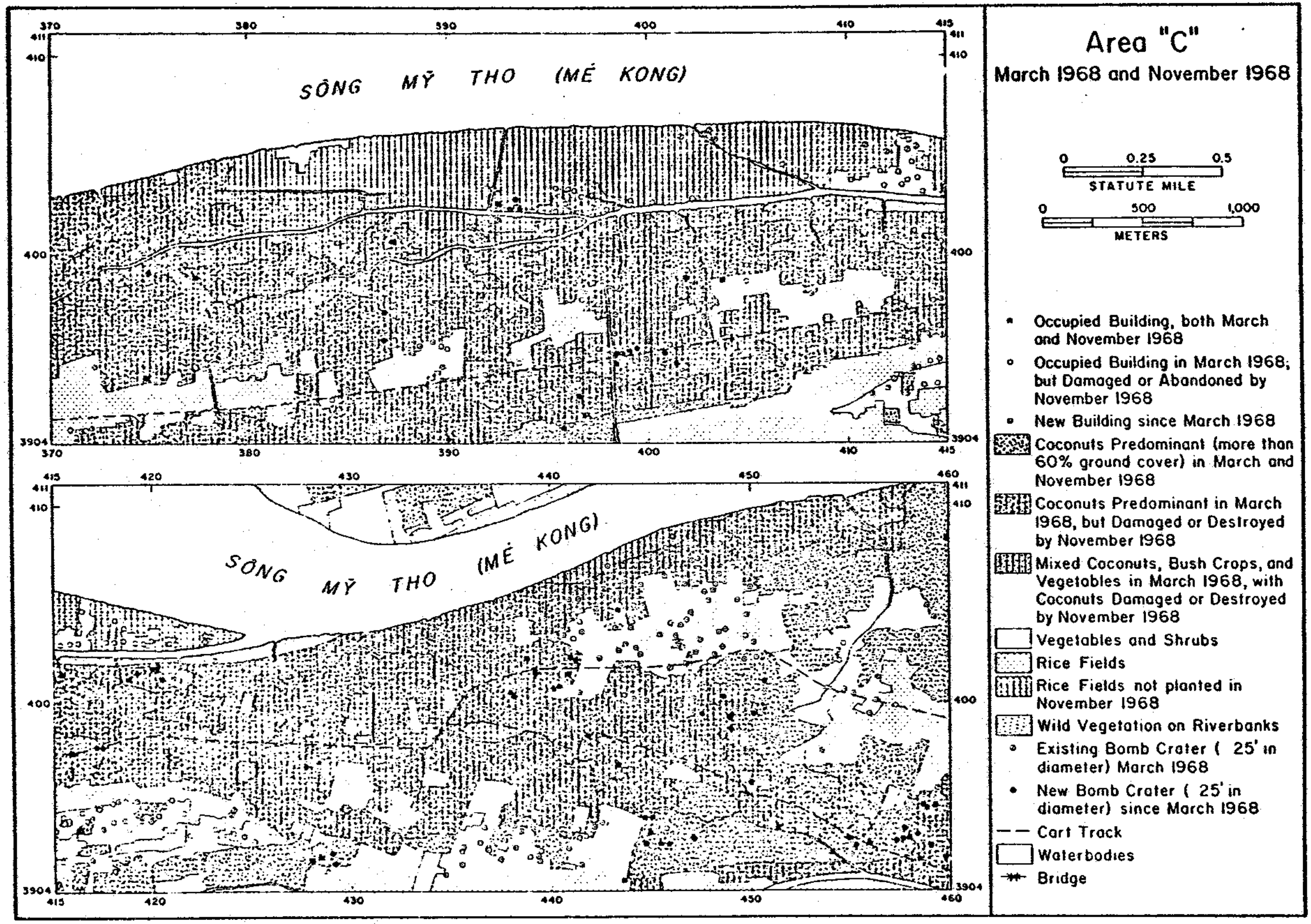


Fig. VII B-5. Detailed interpretation of aerial photographs for Kien-Hoa Province (Study Area 6), (for location of herbicide missions over this study area see Fig. VII B-4) shows a 77 percent reduction in coconut palm acreage and a decrease in occupied houses from 558 to 307 between March and November 1968.

Table VII B-3

Summary of Settlements in the 18 Study Areas that would have been Exposed to the Reported Herbicide Missions

Study Area Number	Total Number of Settlements in Study Area	Number of Settlements Arranged According to the Number of Times that the Centerline of a Reported Herbicide Mission Passed Within One Kilometer of their Centers					Settlements Sprayed as Percent of Total Settlements
		0=not Sprayed	Sprayed 1 time	Sprayed 2 times	Sprayed 3 times	Sprayed 4 or more times	
Mangrove							
1	30	5	2	1	7	15	83.3
2	104	42	15	9	9	29	59.6
3	56	5	4	6	5	36	91.1
4	25	3	2	2	5	13	88.0
Delta							
5	67	34	8	6	1	18	49.3
6	119	57	12	21	20	9	52.1
7	102	26	12	19	10	35	74.5
Plantation							
8	62	6	5	5	12	34	90.3
9	32	18	4	4	2	4	43.8
10	140	122	10	4	2	2	12.9
Lowland Valley							
11	6	0	0	0	1	5	100
12	38	0	0	0	0	38	100
13	108	38	13	18	5	34	64.8
14	11	0	0	0	0	11	100
Upland Valley							
15	17	2	1	3	1	10	88.2
Swidden							
16	53	2	4	7	9	31	96.2
17	69	8	5	8	3	45	88.4
18	37	0	0	0	1	36	100
Total	1,076	368	97	113	93	405	

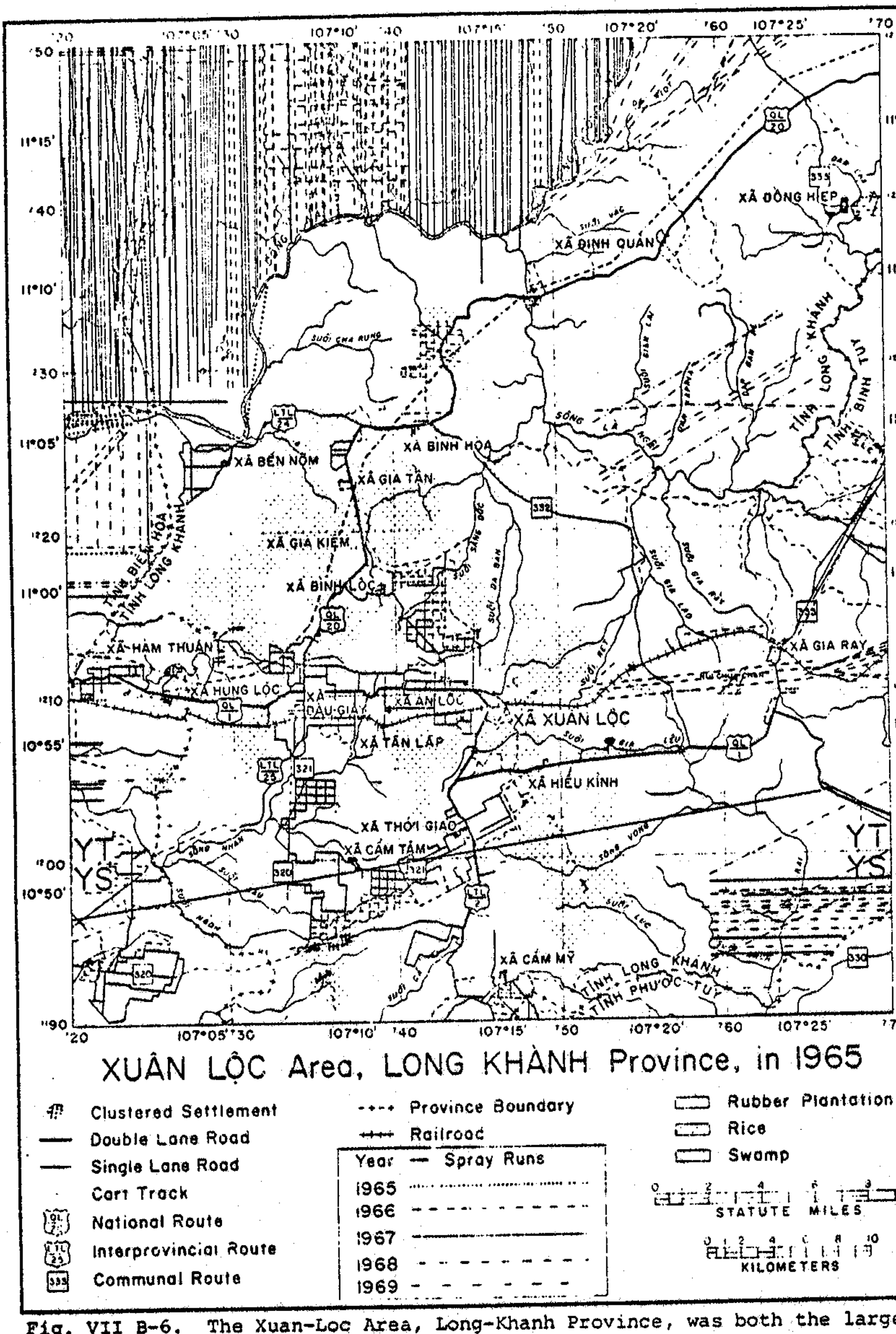


Fig. VII B-6. The Xuan-Loc Area, Long-Khanh Province, was both the largest in size (1,147 square miles) and subjected to the most spraying (313) runs. However, only 18 of its 140 settlements (12.9 percent) were exposed to spraying (see Table VII B-3). Owing to the congestion of herbicide missions and the small scale of the map, detailed data for each run (date, agent, gallons) are not indicated.

Population Displacement. In every one of the 18 study areas, without exception, there was aerial photographic evidence for the displacement of people from their homes following herbicide spraying. To be sure, herbicide missions may have been only one causal factor among many (insecurity, bombing, ground fighting, or other war-related events) that led people to decide to move. An example of massive evacuation of a population and herbicide destruction of crops, fruit trees, and houseyards is provided by Fig. VII B-7, showing the "before-and-after herbicide spraying" in a part of Study Area 12.

Another example is provided by Study Area 8 (see Fig. VII B-2), where the hamlets in the upper left included those evacuated by persons who were resettled in Binh-Hoa (see Section VII B(2), for results of interviews with some of these refugees).

Post-spray photographs were unavailable for most study areas. As far as the evidence permits us to say, only in the Rung Sat Special Zone (Study Area 4) has land use and settlement expanded after cessation of the herbicide operations (Fig. VII B-8). The Rung Sat had in 1972 a larger population than was present when herbicide spraying began.

The cumulative effect of herbicide operations upon the rural countryside has been to displace people from their farmsteads and village homes, forcing their temporary or "permanent" relocation. Insofar as refugees have gone into camps, towns, and cities, the use of herbicides (together with all other war-related activities) has contributed to the massive urbanization of SVN which has occurred in the course of the war.

Land-Use Change in Sprayed Areas. The most heavily affected natural vegetation of those types extensively examined was the mangrove forest along the coast of the Mekong Delta (Study Areas 2 and 3), in the Rung Sat Special Zone (Study Area 4), and to a lesser extent in the Ca-Mau Peninsula (Study Area 1), in all of which, large areas were denuded of vegetation. To be noted here is the aerial photographic evidence that in the inland sector of the Rung Sat (on land farthest removed from tidal submergence) Vietnamese settlers have been removing the stumps and roots of killed mangrove trees, and planting new rice fields. Fig. VII B-8 shows the location and extent of this activity east of Quang-Xuyen and north of Tran-Hung-Dao.

(c) Summary and Conclusions

Since the study areas described here were chosen especially because they had been heavily sprayed, the results of this aerial photo-interpretation study cannot be extrapolated for unsprayed or lesser-sprayed areas, nor can they be used to obtain a nationwide quantitative estimate of total effects. Interpretation of photographic evidence on the effects of the herbicide operations on settlements of different types in the 18 selected study areas (Table VII B-3) leads to the following conclusions:

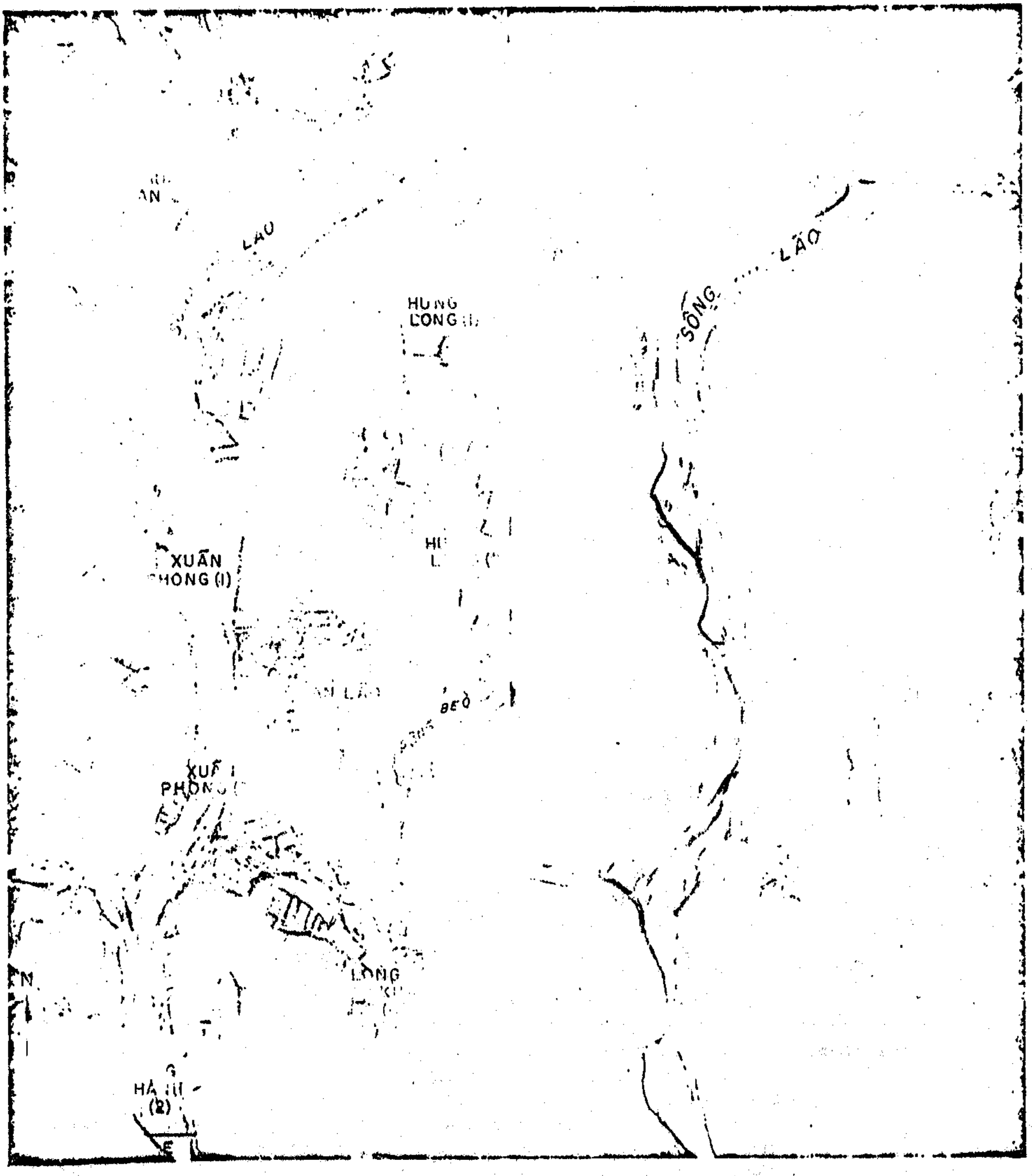
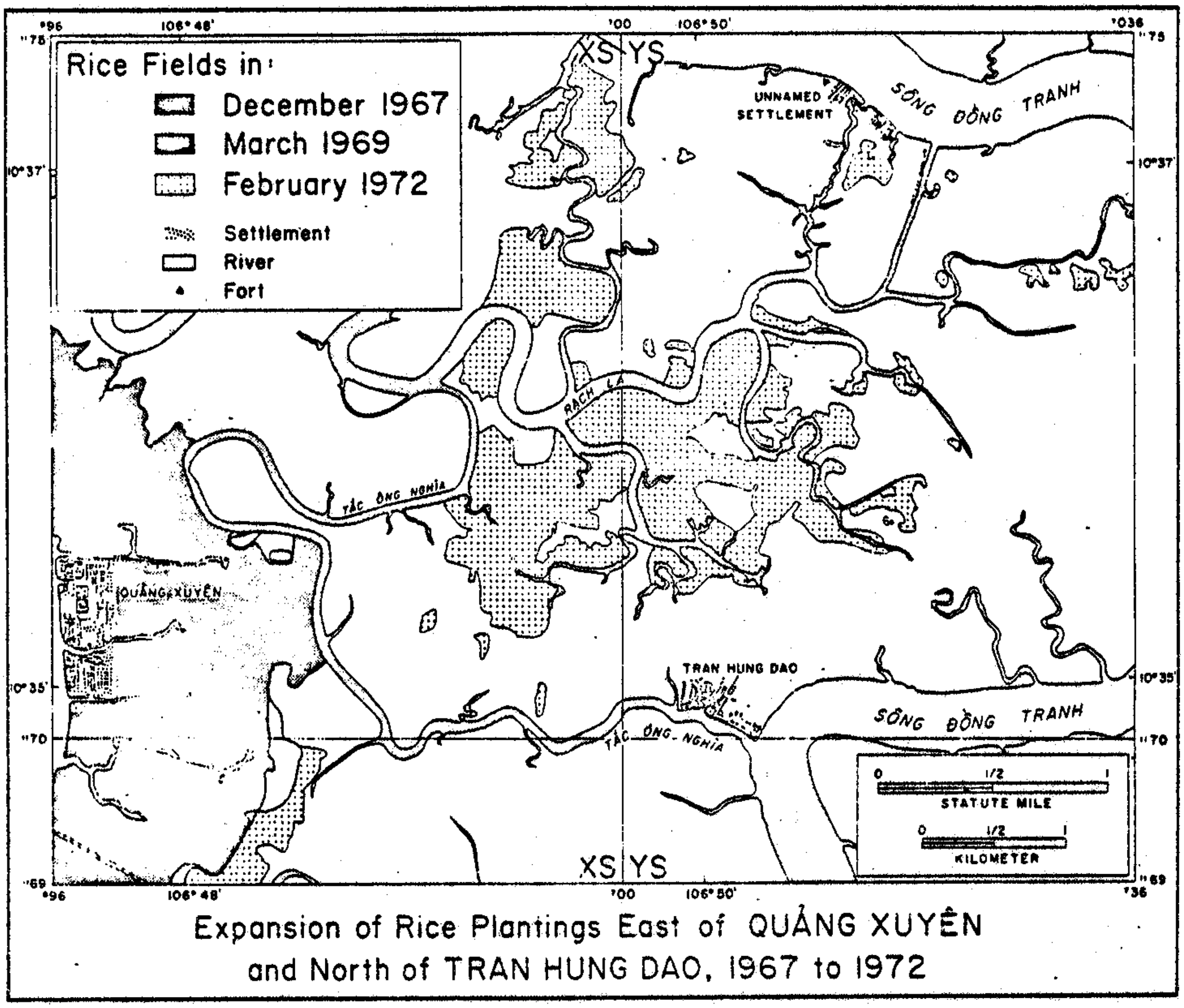


Fig. VII B-7. The densely settled and productively cultivated floor of the An-Lao River valley (Study Area 12) on 28 October 1965 (left), compared to the identical area on 24 June 1968 (right), indicates vast devastation and complete abandonment by at least 6,400 people (915 houses). Ten herbicide missions are reported over this area between 12 March 1967 and June 1968; another nine were flown in late 1968 and 1969, all for the purpose of crop destruction.



Expansion of Rice Plantings East of QUẢNG XUYÊN and North of TRAN HUNG DAO, 1967 to 1972

Fig. VII B-8. An example of land use change since the end of herbicide operations. Here shown is the inland sector of the Rung Sat Special Zone (Study Area 4), for which photographs of 9 February 1972 indicate a wholly new settlement since 1969 and an expansion of new rice fields totalling 900 acres (360 hectares) onto land where the mangrove forest cover had been killed by herbicide spraying.

(1) Many settlements as well as the cultivated tree, bush, and grain crops in fields surrounding the settlements were intensively sprayed. Except for one Study Area (10), many settlements were sprayed repeatedly. Rice, the most important crop, was most commonly sprayed. The most damaging effects of herbicides on commercial crops were in the coconut groves of Kien-Hoa Province (Study Area 6). Most damage or destruction to crops in the study areas resulted from spraying missions designated as defoliation (except for Study Areas 12 and 13 in which crop destruction missions predominated). Agent Orange was used in these areas almost twice as frequently as Agents White and Blue combined.

(2) People in all study areas were displaced from their homes following herbicide spraying. Only in the Rung Sat Special Zone (Study Area 4) have population and settlements increased over the pre-spray period. Elsewhere, the herbicide operations have contributed to the displacement of population of SVN.

(2) Beliefs, Attitudes, and Behavior of Lowland Vietnamese

The purpose of this part of the study is to describe the social, psychological, and economic effects of herbicides on people in several areas of lowland SVN. It includes sections on methods, effects on plants and animals, economic implications, compensation, refugee movement, health hazards, psychological strain, and lastly views on the use of herbicides. The goal is to present what people say they believe and to show the patterning of their feelings. Another concern is to put these beliefs in perspective by examining relevant facts when these are available.

(a) Procedures

This study is based on interviews and documentation which are described in a report of which these pages are a summary. Interviews were conducted with RVN officials at various administrative levels, as well as with farmers, fishermen, market women, etc. The documents consisted of newspapers, magazines, agricultural reports, hospital records, and the findings of a variety of studies carried out by Vietnamese and U.S. scientists. The procedures of the study can be described in three units: provincial studies, Binh Hoa community study, and newspaper analysis.

Provincial Studies

Of the four physiographic regions in SVN, we chose the Mekong Delta Region and the Terrace Region since these encompass the majority of the country's population and its most productive resources. Within each of the ecological zones we focused on a single province as the unit of study: Kien Hoa Province in the Mekong Delta, and Long Khanh Province in the Terrace Region. Work in these provinces was done between July and October 1972. Semi-structured interviews with more than 300 individuals were conducted in 15 of the 19 villages in Long Khanh and 26 of the 115 villages in Kien Hoa.

Data were collected by one Vietnamese and four American social scientists, as well as 17 Vietnamese research assistants. We endeavored to maximize validity by utilizing diverse sources of information, through analysis aimed at detecting inconsistencies, through the participation of Vietnamese with appropriate experience and training, and through the proficiency in the Vietnamese language of some of the American team members.

Attributes of the two provinces are compared in Table VII B-4. A smaller quantity of herbicide was applied in Kien Hoa where there appears to have been direct exposure to people and crops, especially in NLF areas. According to the HERBS information on spraying in Long Khanh, most missions were flown over essentially uninhabited forests located away from populated and cultivated areas. In this province, the people attributed exposure to wind drift from spraying conducted over the forest areas.

Table VII B-4. Characteristics of Provincial Study Sites

Study Unit	Kien Hoa Province	Long Khanh Province
Ecological setting	Mekong Delta	Terrace Region
Vegetation	Rice paddies, coconut groves, mangroves	Upland forest, rubber plantation, cultivated fields
Surface area	2,155 km^2	4,460 km^2
Population (1971)	618,870	166,539
Population density	287 persons/km^2	37 persons/km^2
Ethnic composition	Lowland Vietnamese	Lowland Vietnamese, and a few Montagnards
Settlement pattern	Lineal hamlets and dispersed homesteads	Nucleated, with most of forest areas uninhabited
Economic orientation	Small holder rice, fruit and vegetable farms, coconut groves, fishing	Timber, rubber plantations, small holder fruit, vegetable and rice farms
Population under NLF Control (1968)	Approximately 50% of population	Approximately 10% of population
Quantity of herbicides 1965-1970 (gals.)	276,935	1,639,350
Agent	78% Orange, 22% White	60% Orange, 39% White, 1% Blue
Spray Locales	Chiefly mangroves, coconut groves, and waterways	Principally heavily forested areas
Exposure of people and crops	Direct spraying over inhabited areas, especially those under NLF control	Apparent long-range wind drift from spray runs over forest areas

Table VII B-5

Herbicide Missions in Relationship to Location of Hamlets in Kien Hoa Villages Where Data were Collected [Using a 1 km (0.6 mi) Range]

Village	Hamlet	UTM Coordinates of Village/Hamlet	Date of Mission	Agent	Quantity (gal.)
Phu-Tuc	Phu-Xuan	XS 388398/	1 Apr 1968	Orange	2000
		XS 370395		Orange	2000
Tuong-Da	An-Loc	XS 425385	10 Apr 1968	Orange	6000
	An-Dinh	XS 442375	1 Apr 1968	Orange	6000
Thanh-Trieu*	Phuoc-Thanh	XS 400380	10 Apr 1968	Orange	6000
Thanh-Phong	Thanh-Loi	XR 835940	24 June 1966	Orange	2000
	Thanh-Loc	760863	6 June 1966	Orange	2000
	Thanh-Phuoc	770880	"		
	Giong-Dai	787904	"		
	Dai-Nhon	790917	"		
	Thanh-Loc	760863	27 May 1966	Orange	4900
	Thanh-Hoa	760866	"		
Giao-Thanh*	Giao-Thanh	XR 767949	2 June 1966	Orange	4000
	Giao-Hoa Cho	762934	"		
	Giao-Thoi	XR 817937	23 May 1966	Orange	3700
	Giao-Thanh	767949	"		
	Giao-Binh	797958	"		
	Giao-Tan	XR 753855	27 May 1966	Orange	4900
	Giao-Hoa B	768913	"		
	Giao-Loi	790958	"		
	Giao-Hoa B	XR 768913	6 June 1966	Orange	2000
	Giao-Binh	797958	"		
	Giao-Thanh	XR 767949	22 June 1967	Orange	2790
My-Thanh	Cho-Hanh-Sao	XS 593300	1 May 1969	Orange	4000
An-Nhon*	An-Binh A	XR 735941	22 June 1967	Orange	2790
	An-Dinh	744923	"		
	An-Hoa	741934	"		
	An-Binh B	XR 767050	12 June 1967	White	2400
Chau-Hoa	Phu-An/P.-Thuan	XS 634302	25 Apr 1966	Orange	3000
	Phu-Hoa/P.-Tri	XS 640294	"		
	Thoi-Hoa/T.-Tri	650286	"		
	Phu-An/P.-Thuan	XS 634302	13 Nov 1967	White	2000
	Phu-Hoa/P.-Tri	640294	"		
	Phu-An/P.-Thuan	XS 634302	16 June 1967	Orange	6250
	Phu-Hoa/P.-Tri	640294	"		
	Thoi-Hoa/T.-Tri	650286	"		
	Thoi-Thuan	658273	"		

Map coordinates are for each hamlet.

*Villages for which HERBS tape, aerial photos, ground photos and data collection on the ground are coordinated.

For Kien Hoa it was possible to compare the HERBS tape data with the locations of people who were interviewed. The purpose of this was to estimate the extent to which first-hand observation could have been the basis for the information reported to us. Table VII B-5 shows the HERBS information on missions flown within one km (0.6 mi) of hamlets in villages where interviews were conducted. A hamlet is a smaller administrative unit than a village, and in a densely populated area such as Kien Hoa it is reasonable to assume that what occurs in one hamlet is known to most villagers. Thus, it can be seen that in 8 of the 26 villages studied there is evidence of close proximity to flight paths. Nine other villages studied were in a 3 km (1.8 mi) range. Thus in about two-thirds of the areas where interviewing was conducted it was likely that people had first-hand knowledge. In four of these villages the interview data is supplemented by aerial and ground photographs.

The Binh Hoa Community Study.

Binh Hoa is located in the province of Binh Duong and is inhabited mostly by refugees from the Iron Triangle area in War Zone D who were resettled as part of a U.S. military operation (Cedar Falls) in 1967. Prior to their evacuation and destruction, the native hamlets of the Binh Hoa refugees had been subjected to heavy military activity, including the use of herbicides (see Section VII B-1).

In the study of this group, a systematic sample totalling 92 people was interviewed according to a structured questionnaire format.

Newspaper analysis and literature survey.

Content analysis was done of two newspapers, one pro-establishment and the other anti-government, together with a review of other types of Vietnamese literature. The aim was to gain more understanding of urban middle-sector opinion regarding the use of herbicides.

(b) Beliefs About Effects on Plants and Animals

In all areas studied, people believed that herbicides have damaged or destroyed a variety of crops ranging from manioc and fruit trees to rice. They made no distinction between types of agents and thought of herbicides as a single entity.

By and large, ideas about plant sensitivity parallel what is known from experimental and other sources. Thus, damage to fruit trees was the most commonly reported and the topic about which there was greatest agreement. There was general belief that papaya was exceedingly sensitive and that jack-fruit, coconut, and bananas were also highly susceptible. Among field crops, beans were believed to be very sensitive, and manioc and sweet potatoes were also thought to be easily damaged. A sizeable number of people thought rice could be badly damaged during the pollen formation stage, but there was much less agreement about its susceptibility at other stages.

People in Long Khanh believed that rubber and timber had been affected by herbicides, but reports tended to be inconsistent with regard to the extent of damage sustained.

There seemed to be a general belief that herbicides did no lasting harm to soil. On the other hand, people held that poultry are susceptible after consuming feed or water contaminated by herbicide. Reports on pigs were similar. Illness and death were mentioned, but resistance to herbicide was thought to be related to the physical condition and age of the animals. There was general agreement that cattle and water buffalo were seldom affected.

(c) Economic Implications for Agriculture

As background for estimating the impact of herbicides on the lives of individual Vietnamese, we made two studies of economic implications. One focuses on Long Khanh Province where it was possible to draw certain conclusions from official records. The other concerns Kien Hoa and is based on interviews with coconut growers (see also Section VII B-1).

Official herbicide records show Long Khanh to have been among the most heavily sprayed provinces in the country, with 1967 as the peak year. The Provincial Agriculture Report for the year indicates a drop of about one-third from normal crop yields per hectare. Three reasons for the drop were given: herbicides, Rome plowing, and the take-over of land by RVN and Allied/ U.S. forces. Villagers and local officials also expressed the belief that herbicides had been a major causal factor. It is not possible to factor out the role of herbicides from that of other causes, but the combined effects can be examined.

Did people in Long Khanh have enough to eat in 1967? Rice consumption declined but on the average remained above general Asian standards. On the whole, severe physical deprivation did not result, thanks to alternative sources of income in the war-inflated economy. The "average, of course, conceals a great deal. Data limitations preclude systematic study of the question of how many people lost how much. Instead, we assumed an average yield decline for various crops and calculated illustrative economic consequences for two types of farmers--the owner-operator and the sharecropper. For this purpose it was necessary to translate the provincial information into terms which have meaning for an individual farmer. The concept of "disposable income" is utilized as the market value of agricultural output after purchased inputs such as seeds and fertilizer have been deducted. Thus, when it is indicated that an owner-operator farmer has an expected disposable annual income of 21,400 piasters for one hectare of rice, it means that the crop has that monetary value whether the farmer uses it for family consumption or sells it. From such calculations, it is possible to offer "order of magnitude" estimates of loss as shown in Table VII B-6.

Table VII B-6. Estimated Household Disposable Income in 1967 for Prototype Farm Units (In Piasters)[a]

	One-Hectare (2.5 acres) Plot		Three-hectare (7.5 acres) Plot		Loss of Disposable Income (%)
	Expected	Achieved	Expected	Achieved	
Owner-Operators					
Sweet potatoes	67,800	10,000	203,400	30,000	85
Manioc	48,700	5,900	146,100	17,700	88
Mung beans	41,100	6,600	123,300	19,800	84
Peanuts	31,700	5,100	95,100	15,300	84
Soybeans	27,500	7,400	82,500	22,200	73
Rice	21,400	7,300	64,200	21,900	66
Sharecroppers					
Sweet potatoes	52,400	6,600	157,200	19,800	87
Manioc	36,700	3,000	110,100	9,000	92
Mung beans	30,300	3,900	90,900	11,700	87
Peanuts	24,000	2,500	72,000	7,500	90
Soybeans	19,500	4,000	58,500	12,000	79
Rice	16,100	5,100	48,300	15,300	68

---

a The values shown here are derived from the Long Khanh Agricultural Report of 1967. The numerous steps of calculation which lie behind this summary are detailed in Part B of the Committee's report.

In interpreting these piaster results, dollar conversions are virtually meaningless. Instead, we have used various existing economic studies to calculate an indigenous welfare indicator (compare Sampson, 1970; and Stanford Research Institute, 1968). On this scale, an annual income of 20,000 piasters indicates "subsistence," an income of 65,000 piasters is "comfortable," and anything over 100,000 piasters qualifies as "rich" by provincial Vietnamese standards. Table VII B-6 suggests that for the small owner-operator the loss of disposable income would have ranged from 66 to 88 percent depending on the crop. A three-hectare rice farmer moved from a comfortable level of income to the boundary of subsistence. A one-hectare rice farmer moved from "subsistence" to "very poor." At this level, starvation would be unavoidable without alternate employment, borrowing, assistance from the extended family, or government relief. For sharecropping tenants, the story is similar. The losses would have ranged from 68 to 92 percent. Since tenants are closer to subsistence to begin with, the welfare implications are greater.

For growers of perennial crops such as coconuts, a different sort of analysis is required. We studied this problem in Kien Hoa Province where many growers were said to have suffered total loss. Others apparently sustained drift damage, but were not severely harmed in terms of current income since the price of coconuts tended to rise. All owners, whether directly affected or not, experienced a decline in wealth due to a drop in the value of their land, as shown in district records in Kien Hoa. Thus coconuts became an increasingly risky crop--not only because of the herbicides, but also because of war activity in general. Unlike the annual crops, significant long-term damage occurred because the loss of trees meant no production for at least 5-7 years and, more importantly, the war precluded replanting and upkeep.

(d) Compensation

It was the stated intent of the RVN to reduce the unfavorable impact of herbicide damage by providing compensation for destroyed crops. This intention does not, however, appear to have been uniformly translated into action.

In Kien Hoa we were able to examine documents and consult officials to ascertain how the compensation program was organized. Two channels were available for seeking compensation; one for claims under 100,000 piasters and another for claims over that amount. The apparatus was obviously unwieldy and it is not surprising that eight months or more were often required to complete a claim.

The proportion of compensation in relation to actual loss was very low. A Kien Hoa coconut grower, for example, with a one-hectare (2.5 acres) plot of 250 trees totally destroyed by herbicides could claim a maximum compensation of 25,000 piasters. Yet, if we take 1968 prices, such a plot would have yielded an annual income of 97,800 piasters. If a grower had sought compensation in 1969 he would still have received 25,000 piasters. With inflation, his trees would have yielded him a crop worth 138,000 piasters by that time.

In Long Khanh we were unable to determine the exact nature of the provincial administrative machinery used to process claims. The villagers in this province were, however, much more resentful than in Kien Hoa. People were dissatisfied with the amount of payments, but in addition, they believed that only a few favored individuals received compensation due to corruption, the complexity of the claim filing process, and the cost involved in processing the paper work. However, the fact that high officials believed wind drift could only occur over short distances and thus would not consider many claims appears to have been a principal obstacle to a just and effective compensation program.

(e) Refugee Movement

The relocation of people has been one of the most pronounced human effects of the Vietnam war. While it is likely that the part played by herbicides varied in different sections of the country, in Long Khanh and Kien Hoa only a few respondents cited herbicides as an explanation for refugee movement. Indeed, some respondents stated that it would be pointless to try escaping herbicides by shifting location because no matter where they went they would still risk the possibility of herbicide exposure. These findings are in agreement with the major refugee studies that have been done in SVN.

(f) Health Hazards

The problem of birth anomalies has been dealt with earlier in this report (see Section VII A-1). While working in the two provinces, we investigated the possibility of using hospital records to address this question. Records were non-existent except for the most recent two years and even then they lacked information on total number of births from which the proportion of birth defects could be estimated. Our interviews with doctors, nurses and lay people on the topic indicated that many persons had heard rumors that deformed babies may be caused by herbicides, but no one held this as a firm conviction based on what to him would be acceptable evidence. While this information does not refute the possibility of fetal damage, it does indicate that the sources which could be consulted by our methods did not offer any positive indication of such a consequence.

On the other hand, a variety of immediately painful and disagreeable symptoms associated with herbicides were described by many people. These can be grouped in five categories: (1) respiratory symptoms (coughing, shortness of breath, soreness of throat, inability to breathe, coughing blood, bleeding from the nose, etc.); (2) central nervous system symptoms (headaches and dizziness); (3) gastro-intestinal symptoms (diarrhea, nausea, and stomach ache); (4) dermatic and ocular symptoms (skin sores, rash, and eye irritation); and (5) generalized symptoms (pain, fever, fatigue, trembling, perspiring, palpitations, and general soreness).

In the systematic survey of refugees at the Binh Hoa settlement in Binh Duong Province, each person was asked, "Have you ever been made ill by herbicides?" "If so, how?" Forty-eight subjects (i.e., 52 percent) responded by giving one or more of the symptoms listed above. Respiratory, central nervous system, and generalized symptoms were the most common while disturbances of the gastro-intestinal tract, skin and eyes were less frequently reported.

In Long Khanh and Kien Hoa both direct exposure and drift were seen as noxious, and all of the symptoms except respiratory and dermatic-ocular responses were also thought to be possible consequences of eating food or drinking water which had been contaminated. It is generally believed that most people will recover from the physical disabilities caused by herbicides, yet a large number of interviewees indicated that some people were especially vulnerable while others were resistant. Many individuals believed that the old, the sick, and especially children were likely to experience illness.

(g) <u>Psychological Strain</u>

Psychological strain is one type of effect which results from threats to human well-being or survival. Strain may sometimes become a long-lasting pattern of anxiety, depression, apathy, anger or other emotional state which then often prevents successful adaptation. Among the Binh Hoa refugees we administered a questionnaire, technically referred to as the Health Opinion Survey (HOS), which indicates levels of psychological strain. Within the last 15 years this questionnaire has been applied to over 2500 people in North America and West Africa. The Binh Hoa refugees have a significantly higher score on the average than any other randomly selected sample with which we were able to compare them. None of the other samples, however, had undergone such a high degree of stress as the Binh Hoa people who were subjected to bombing, ground maneuvers, herbicide spraying, evacuation and resettlement, as well as numerous other effects of war.

Using a widely employed social-psychological technique called the Self-Anchoring Scale, we endeavored to place the Binh Hoa refugees' assessment of their conditions of life in relation to other Vietnamese groups. On a scale of 10 (with 10 representing the best possible circumstances and 1 representing the worst) Binh Hoa people on the average rate themselves at 2. Residents of two other Vietnamese villages which had not experienced such an intense level of war stress rate themselves at 4. A sample of U.S. citizens rate themselves as 6. Thus, the Binh Hoa people see themselves in a position of greater disadvantage than the other groups, and we interpret these ratings as confirming that the Binh Hoa refugees have experienced extraordinarily high levels of stress. It seems probable that their high HOS scores are at least partly the psychological outcome of these experiences.

If this interpretation is correct those individuals in Binh Hoa who have borne the largest number of the hard knocks of war should be the ones exhibiting the highest HOS levels of strain. If exposure to herbicides can be isolated as a separate and specific hard knock, we can perhaps weigh the relative influence of herbicide stresses and other war stresses. To this end we developed a Herbicide Stress Scale which concerns adverse health and economic effects attributed to herbicides, and a War Stress Scale which refers to death of relatives, having relatives in military service or prison, etc. The relationships between psychological strain and the different kinds and degrees of stress are shown in Table VII B-7.

Table VII B-7
Mean HOS Scores with Type and Degree of Stress

Type and Degree of Stress	Sample Size	Mean HOS Scores
Low Herbicide-Low War	27	30.6
Low Herbicide-High War	22	33.0
High Herbicide-Low War	20	32.7
High Herbicide-High War	23	34.8
Total	92	32.7

Those people who reported no ill effects from herbicides and who experienced little war stress compared to the others at Binh Hoa have a score of 30.6. Those who perceived themselves as having suffered from herbicide spraying and who also experienced a high degree of war stress have a score of 34.8. From the statistical point of view, the probability of this difference occurring by chance is one time out of a hundred, and we conclude that herbicide operations have played a discernible role among the correlates of psychological scars.

(h) Views on the Use of Herbicides

Our findings indicate that there is a major dichotomy between the views of the rural population and those of the urban middle-sector regarding the use of herbicides in SVN. Contrary to what might be expected, the herbicide missions are a much less emotional issue among the peasants, who bore the brunt of the effects, than it is among urban intellectuals for whom it has become a symbol.

Peasants

Studies of the Vietnamese peasant suggest that he, like many other peasants around the world, is a pragmatist concerned with physical and economic security for himself and his family. In keeping with this, our findings indicate the people in areas not exposed to herbicides operations have relatively few attitudes about them, and those they do have are of low intensity.

On the other hand, the rural population living in or quite close to sprayed areas have concrete and detailed beliefs about herbicides. They consider the main consequences to have been economic loss to farmers and fruit growers. Very few thought of damage as permanent in an ecological sense. Villagers were both angered and saddened by the loss of their crops, but such feelings resulted from the loss and were not specifically because herbicide was the damaging agent. Although most people did not express value judgments about herbicides, they believed that the Americans were responsible for the spraying. For the most part spraying was accepted as a fact of life, one part of a larger situation which was deplorable and defied comprehension.

Despite extensive propaganda and counter-propaganda campaigns waged by the RVN and the NLF, peasant views regarding herbicide effects seem to be based upon their own experience. The RVN stressed that herbicides were used as a military measure to deprive the guerrillas of their hiding places, that the herbicides might damage crops but could also have beneficial effects, and that people and livestock would not be adversely affected by spraying. NLF statements emphasized the dangerous nature of herbicides. They claimed that the chemicals caused the death of people as well as livestock and crops, resulted in increased numbers of miscarriages and stillbirths, and caused numerous diseases, especially leprosy and conjunctivitis. Further it was said that the U.S. had deliberately introduced "chemical bacteria" into the spray which could penetrate people's bodies and cause disease. The fact that the villagers did not appear to subscribe blindly to the propaganda claims of either side does not mean that they lacked political opinions nor that they were uninfluenced by information derived through the mass media. Rather it seems to mean that their opinions on this issue came mainly from their own observations.

Urban Middle Sector

In contrast to the peasants, an important segment of the urban middle sector has come to believe that as the direct result of the herbicide operations, lasting and widespread ecological damage has been done, the health of the rural people has suffered (including instances of death, paralysis, birth defects, miscarriages, and a variety of strange diseases), many refugees have been created, and the national economy has suffered severe, long-term impairment.

The above conclusion is based on an analysis of the content of newspapers and magazines that are inferred to reflect the attitudes and beliefs of the urban middle sector as a whole. Numerous formal and informal interviews with educated Vietnamese in Saigon support this inference.

The media analysis may be described in the following terms. A sample of daily editions of two principal papers (one pro-establishment, and one anti-government) was selected for the period 1965-1972, and categories representing 39 war-related topics of concern (including herbicides) were constructed for coding purposes. The sample was then examined to determine the number of lines devoted to each topic. A second approach attempted to determine the frequency of articles on herbicides usage and the attitudinal content of such articles. Every available issue of the pro-establishment paper from April 1964 to July 1972 and of the anti-government paper from June 1967 to July 1972 was scanned for articles discussing herbicide usage.

In terms of the number of lines printed over the years analyzed, news reporting of herbicide in the pro-establishment paper ranked 29th of the 39 news topics coded, and in the anti-government papers, herbicide renked 23rd. Editorially, herbicide ranked 26th in the pro-establishment paper and 29th in the anti-government papers. Table VII B-8 presents a composite view of the quantitative saliency of the topic of herbicides, compared with several of the other news topics which were examined. It can be seen that regarding space devoted to reporting, herbicides rank low in comparison to topics such as ground combat and military casualties.

In regard to content, reporting was objective and non-evaluative, prior to 1969. This occurred despite the fact that 1967 and 1968 account for a very high proportion of the total amount of herbicides used in the Vietnam war. Beginning in the spring of 1969, however, many more articles about herbicides began to appear, and the greatest increase took place in the opposition press. Not only did the number of articles increase, but quite suddenly attitudes appeared which were exceedingly critical, and there was a spurt of reporting of alleged adverse effects. As seen in Table VII B-9 this trend continued through 1970 and 1971 after large-scale military use of herbicides had been discontinued.

The shift in content and tone was marked by a series of articles in Tin Sang (anti-government) claiming that Vietnamese women were giving birth to "eggs." More articles followed linking birth defects, miscarriages, and other health problems to herbicides. As for belief in the effects upon animals, Tin Sang moved from reporting that herbicides were not harmful (January 27, 1969) to the following statement: "In the defoliated areas of South Vietnam most farm animals are dead. Pigs, chickens, ducks, bees, frogs, fish, and snakes--all have disappeared. Those that are still alive are weak and unable to reproduce." (February 2, 1969).

Herbicides were also mentioned as contributing to the generation of refugees and by mid-1970 concern was being shown for the more general ecological effects. At the conclusion of a long and objective article on herbicide use in SVN, Chinh Luan (pro-establishment) (August 25, 1970) said:

> "A large area of land has been sprayed with defoliants and the long-term effects have not been definitely assessed. Nevertheless, the excessive spreading of a number of strange chemical substances into the botanical environment will certainly affect the ecology, and chain reaction could cause a depletion of the nation's natural resources."

Table VII B-8

News Reporting: A Comparison of Herbicide and Some Other Selected Topics

Topic	1965	1966	1967	YEAR 1968	1969	1970	1971
Herbicides	0.03	0.01	0.19	0.07	0.78	0.38	0.43
Military Casualties	11.80	10.20	11.30	12.30	10.70	9.00	9.30
Ground Fighting (RVN)	16.80	13.70	15.10	19.60	15.20	9.40	9.80
Terrorist Action	8.60	10.10	7.80	6.40	6.30	3.10	2.10
Loss of Weapons	0.17	0.09	0.23	0.09	0.06	0.03	0.02
U.S. Build-Up	1.10	0.54	0.90	0.12	0.37	0.01	0.06
Vietnamization	0.00	0.00	0.00	0.08	0.57	0.36	0.71
Population Movement	0.62	0.36	0.77	1.50	0.24	0.61	0.06
Anti-U.S. Sentiment	0.23	0.83	0.16	0.02	0.00	0.97	2.58
Cost of Living	0.23	0.66	1.10	0.49	1.10	0.88	1.90
Blackmarket	0.53	2.70	0.29	0.77	0.59	0.56	0.36
Peace Moves	5.60	6.10	8.30	5.80	4.50	3.10	3.10
TOTAL LINES CODED	17389	19588	16407	41544	38819	28185	28674

The numerical value is the percentage for a given topic of the total lines coded for a given year. Thus, herbicides account for about 3/4ths of one percent (.78) of the total output of coded news lines in 1969. The columns for 1965-1967 refer to the pro-establishment press only. The anti-government paper was coded for only a portion of 1967 and is not included for that year. The columns for 1968-1971 combine data from both presses. Since only a portion of the 1972 papers from both pro-establishment and anti-government was analyzed, that year is also not included in this tabulation. The percentages for the 27 other topics not selected for this table appear in Part B of the Committee's report.

Table VII B-9

Selected Attitudes About Herbicides
in the Pro-Establishment and Anti-Government Press

	1968	1969	1970	1971
Objective reporting of statements about herbicides without editorial comment	50% / 17%	50% / 17%	33% / 4%	25% / 18%
Doubting the advantages of herbicides as compared to disadvantages, etc.	0% / 17%	0% / 7%	42% / 16%	37% / 13%
Critical of RVN because of herbicides, failures of compensation program, etc.	0% / 67%	0% / 56%	0% / 20%	0% / 24%
Critical of U.S. because of harmful effects of herbicides on crops, humans, environment, etc.	0% / 17%	0% / 28%	0% / 92%	12% / 69%
Total number of articles	6 / 6	6 / 43	12 / 25	8 / 45

The percentage of articles from the pro-establishment press which display a given attitude appears in the upper left hand corner of each cell: 50%

The anti-government percentages are in the lower right: 17%

The pro-establishment articles in 1965, 1966, and 1967 were similar to what is shown for 1968. The anti-government articles reviewed for half of the year 1967 were similar in number and attitudes to 1968. Table VII B-9 is limited to the four years for which we were able to make a year-long review of both papers.

The four attitudes shown here are a selection from the 14 categories used for coding purposes. The remainder are shown in Part B of the Committee's Report.

There was belief by some writers that the soil may have been permanently affected and the vegetation destroyed or irremediably altered in certain areas. Floods were blamed on herbicides and eventually it was alleged that herbicides change the climate.

The extent and significance of the change in view is demonstrated by an article which appeared in Chinh Luan just before the 1971 elections. Raising what they termed "the people issue," Chinh Luan in effect demanded that Thieu and Huong demonstrate their willingness and ability to stand up to the Americans and exert more control over American actions in SVN. Chinh Luan's editors' beliefs regarding the use and effects of herbicides in SVN were an explicit and major factor in a more general disenchantment with the U.S. performance in the country:

> "The U.S. Armed Forces have a low regard for the lives and property of the people of this country. As a result much indiscriminate bombing has taken place, and careless herbicide spraying has been conducted, a spraying that is beyond the real and reasonable tactical needs... Indiscriminate defoliation activities of the U.S. Armed Forces have inflicted great damage upon trees and crops which are a source of life to the people."
>
> (Chinh Luan, September 29, 1970)

Such a statement in this prestigious, normally pro-American newspaper is a striking demonstration of the extent to which attitudes and opinions had changed on this issue.

In April 1972, a journal whose editorial board includes numerous non-Communist scholars and intellectuals, Trinh Bay, published a special issue on "The American Destruction of Indochina." This presentation was prefaced by an introduction which informed the readers that they were being given reports of research on herbicides which were:

> "... actually carried out by American specialists and scientists and publicized in the United States, which are relevant to the present American war policy in Vietnam--a policy which we wholeheartedly oppose because of its cruel and senseless nature, and because it is contradictory to the very goals which the Americans themselves loudly proclaim: the defense of the Vietnamese people, defending by exterminating the very people one wishes to protect! Especially when we note the aspect of the long-term destructiveness of that policy upon our land."

Our conclusion is that among the urban middle sector herbicides had become a symbol through which fear, anger, and resentment toward the U.S. are both expressed and stirred. The importance and weight of this symbol is most evident in the content and emotional tone of the articles rather than in their frequency, although this too had increased. The point had been reached where a poet or writer seeking to express complex emotions about the impact of the Americans in Vietnam, or perhaps of the war in general, would often select herbicides as a symbol.

(i) Summary and Conclusions

To summarize this material on beliefs, attitudes, and behavior among the Lowland Vietnamese, it would seem that herbicides induced a number of harmful effects. These related not only to the fact that people perceived damage done to crops and animals but also that for some people there appears to have been ill effects upon their economic status as well as physical and emotional health.

We believe the contrast between the views of the peasants and the city dwellers is one of our most important findings. Those people in the countryside who had experience with herbicides hold the pragmatic belief that herbicides are a bad thing among the many bad things that have occurred as a result of war. In the urban centers strongly held feelings developed in which herbicides came to be an emotionally charged symbol that stands for many apprehensions and distresses, but especially those for which Americans are blamed.

We attach importance to this because the urban middle sector is politically influential. Further, it is our interpretation that in the long run their views will influence the peasants rather than vice versa. It is not so much that the peasant will change his mind about herbicide effects but rather he may begin to share the symbolic meaning. The fact that herbicides have become a symbol does of course not mean that they are the cause of the rise of negative attitudes thereby represented--nor even the most important factor among a complex of factors. It does, however, mean that the power of this symbol to mobilize and articulate feelings is one aspect of the herbicide impact on SVN.

REFERENCES

Sampson, Robert L., 1970. The economics of insurgency in the Mekong Delta of Vietnam. The M.I.T. Press, Cambridge, Mass.

Stanford Research Institute, 1968. Land reform in Vietnam, Vol. V. The hamlet resident survey.

(3) Perceived Effects of Herbicides in the Highlands

The purpose of the research on the Highlands was to assess the perceptions of Montagnards concerning the effects of herbicides. Due to the timing of this study and problems of security, it was not possible to check the views of these people by observations on plants and animals or by medical examination of people.

The techniques used in this study were intensive interviews with over 30 key Montagnard informants from twelve villages who had been relocated in five refugee centers in Kontum, Pleiku and Darlac provinces. Location at the time of interview, original location, ethnic background, and characteristics of the interview subjects are listed in Table VII B-10. These people had been relocated as a result of the Spring 1972 offensive. The people interviewed represented several ethnolinguistic groups: Halang, Jarai Arap, Jarai To-Buan, Rengao, and Sedang. A Hroy Highlander, who had been trained in Hanoi as an agricultural engineer and had served as an agricultural advisor with NLF forces in the border area before defecting to the RVN side, was also intensively interviewed. Interviews were conducted by an American anthropologist with over a decade of experience in Vietnam. He used the advice and assistance of interpreters all of whom were employed by the U.S. Government at the time of the research. They spoke the various dialects involved, and translated into English or French. At times the anthropologist talked directly in Vietnamese with interview respondents.

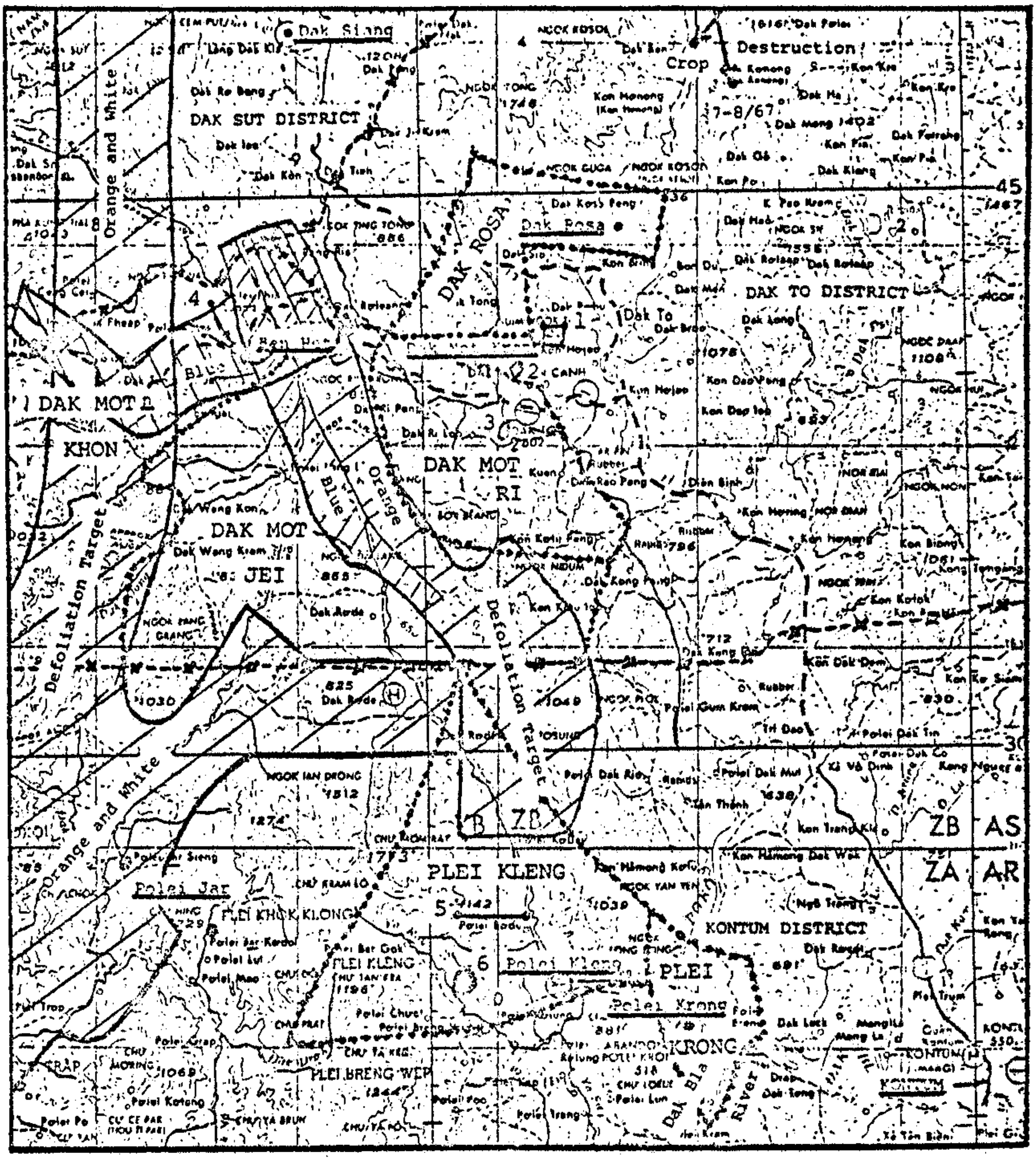
The interpreters were briefed prior to the interviews to clarify terminology and references to various kinds of herbicide sprays and effects. Interview subjects were sought from locations believed to have been sprayed on the basis of recorded herbicide mission data. An attempt was made to locate as precisely as possible both the settlements and swiddens of the respondents and the herbicide missions to which they were exposed. A comparison of herbicide mission data from HERBS tape printouts with areas inhabited by the respondents suggests that they were living in close proximity to targets for defoliation and/or crop destruction missions. The greatest distance any group of settlements appear to have been from target coordinates is about 15 km or 9 mi (see Figs. VII B-9, B-10, and B-11).

Respondents were asked about settlement patterns, locations of farming areas, types of crops grown, and other economic activities. They were then asked about their perceptions of spraying: whether or not they had seen the aircraft, and their perceived effects of the spray. Interviews were repeated with respondents in the Dam San Refugee Center, and with the group at Plei Don in Kontum Province (I and III in Table VII B-10). The subjects were very responsive, their general opinions regarding herbicide effects appeared clear, though their quantitative information was sometimes vague. The respondents were in general agreement that there had been many herbicide operations on or near their settlements and swiddens since 1967. This was confirmed by herbicide mission records which show that the major spraying effort near the respondents began in

Table VII B-10

Characteristics of Persons Interviewed in the Highlands

Location of Interviews	Original Village of Respondents	Ethnic Group	Characteristics of Principal Interview Subjects, Principal Respondents
I. Dam San Refugee Center, Darlac Prov.	1. Long Djon, near Dak To Distr. Hq., Kontum Prov.	Sedang	Two young men, one older woman
	2. Dak Rosa, near Dak To, Kontum Prov.	Sedang	Older man
	3. Dak Tang Plun, near Tan-Canh, Dak-To Distr., Kontum Prov.	Halang	Several older men, several women, two younger men
	4. Plei Ro-O near Polei Kleng, 30 km west of Kontum City	Jarai Arap	Young man (NLF defector) Several women
II. Mary Lou (Ngok Long) Refugee Center, Kontum Prov.	1. Dak Mot-Khon, west of Tan Canh, Dak To District, Kontum Prov.	Sedang	Village chief
	2. Dak Mot-Tri, west of Tan-Canh, Dak To District, Kontum Prov.	Sedang	Hamlet chief
	3. Dak Siang Ranger Camp Dependent's Settlement, northwest of Dak To Distr. Hq., Kontum Prov.	Halang	Young woman, her father, older man, older woman
III. Plei Don Refugee Group	1. Polei Krong cluster of villages, west of Kontum City	Jarai Arap Halang Rengao	Man Man Man
	2. Polei Krong, cluster of villages, west of Kontum City	Rengao Jarai Arap	Older men Older men
IV. Prisoner of War Refugee Center, Pleiku Prov.	1. Polei Kleng, west of Kontum City	Jarai Arap	Young hamlet chief Older woman Older man
	2. Plei Jar Tum, west of Kontum City	Jarai Arap	2 men 3 women
V. Camp Enari Refugee Center, Pleiku Province	1. Plei Ea Tung Hamlet, Plei Ngol-Drong Village near Edap Enang Resettlement Center, Rte. 19	Jarai To-Buan	2 men
VI. Highlander	Phu-Bon and Phu-Yen	Hroy	Man, follower of Viet Minh, moved to North in 1954, trained as Agricultural Engineer in Hanoi University, returned to highlands area astride Phu-Yen/Phu-Bon border in 1969, organized food production for NLF, had "rallied" to GVN at time of interview.



Boundary:
District - - - - - -
Village ....

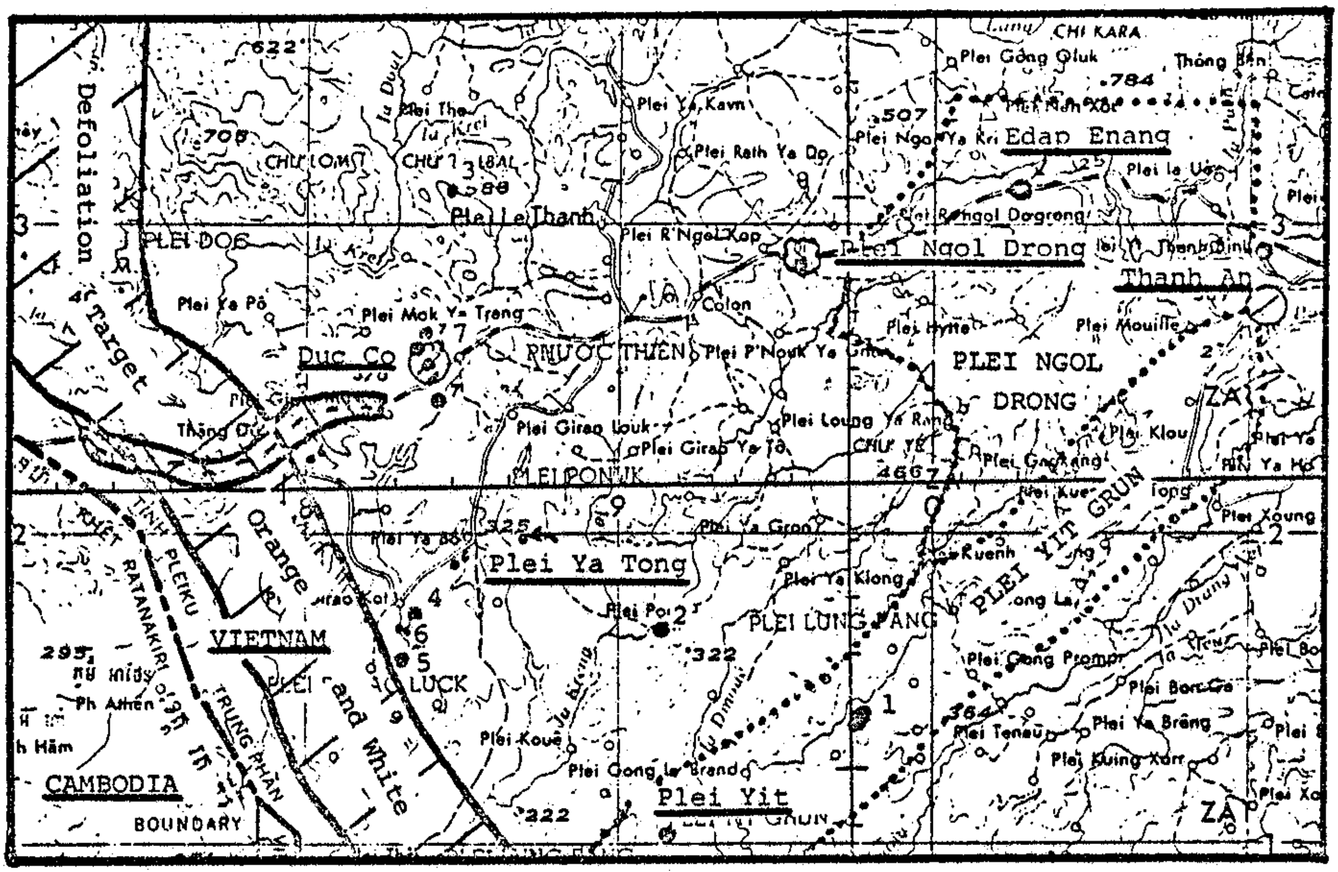
0 5 10
Kilometers

Scale: 1:250,000

<u>Key to Special Targets</u>

1. Aug 68 - 800 gallons White - NLF cache site
2. Aug 68 - 100 gallons White - Military perimeter
3. Aug 68 - 100 gallons White - Military perimeter
4. Aug 67 -1100 Gallons Blue - Crop destruction
5. Nov 68 - 200 gallons White - Military perimeter
6. May 69 - 770 gallons White - Military perimeter

Fig. VII B-9. Informant Settlement Areas and Herbicide Missions in Kontum Province



0 5 10
Kilometers

Scale: 1:250,000
Boundary:
Village ....

Key to Special Targets:

	Agent White		Objective
1.	27 Sept 68	- 550 gallons	- Enemy cache site
2.	24 Oct 68	- 100 gallons	- Crop destruction
3.	28 Oct 68	- 100 gallons	- Military perimeter
4.	29 Oct 68	- 100 gallons	- Military perimeter
5.	1 Nov 68	- 100 gallons	- Military perimeter
6.	10 June 69	- 220 gallons	- Military perimeter
	Agent Orange		
7.	6-30 Nov 65	- 5800 gallons	-Defoliation near Highway 19*

*Only one target coordinate given for each of the five missions.

Fig. VII B-10. Informant Settlement Areas and Herbicide Missions in Pleiku Province.

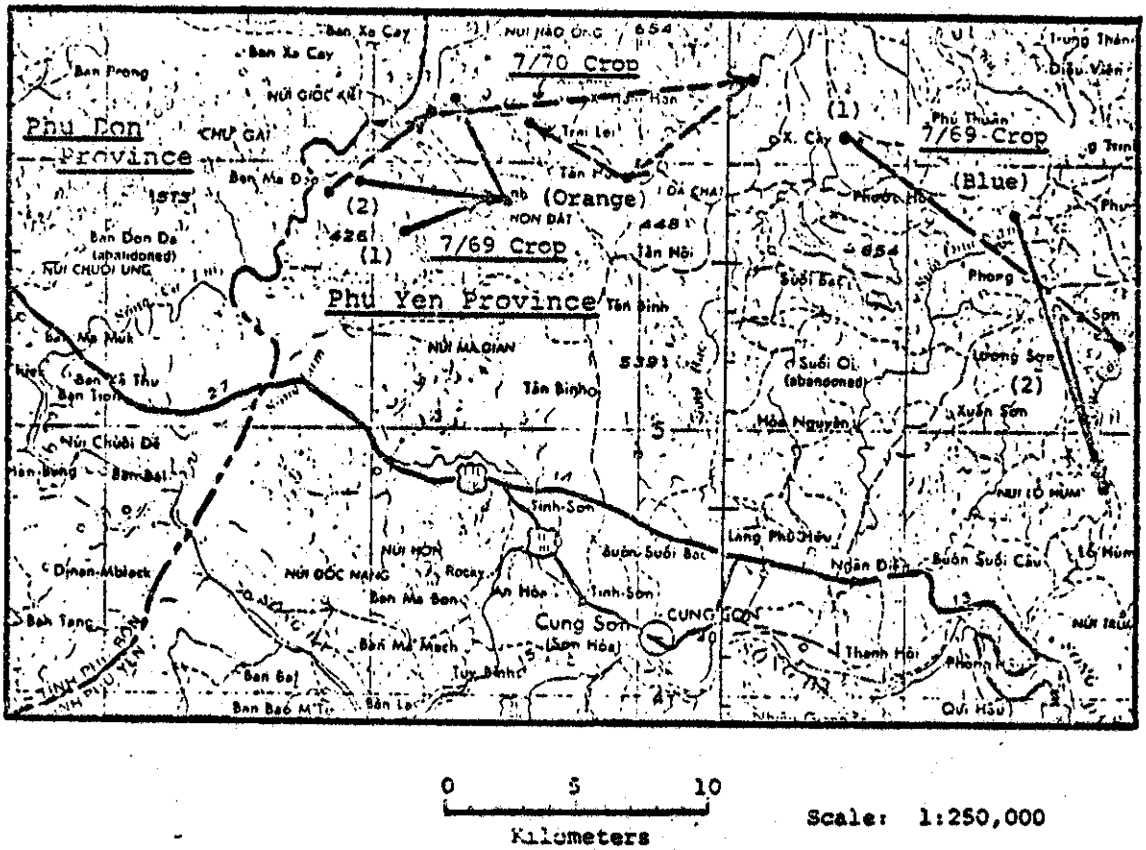


Fig. VII B-11. The NLF Food Production Area Phu Yen/Phu Bon Border Region.

1967 and ended in 1970. Information on general agricultural patterns of the groups represented had been gathered in previous ethnographic field work since 1965.

(a) Agricultural Practices

Among the Highland people of SVN, a wide variety of agricultural practices is found, ranging from wet-rice paddy farming such as is found among the Vietnamese, to swidden farming. All of the villagers interviewed in this study rely on the swidden technique, and this also was the method employed in NLF food production in Phu-Yen Province as described by the Hroy respondent.

Although the swidden farming techniques vary from group to group, there are some common basic characteristics, particularly among the groups in Pleiku and Kontum. Essentially, swidden farming in Highland SVN is a system of rotating agriculture wherein a given field is cleared, the cut wood burned, and the land afterward farmed for a duration of years that depends on the adjudged fertility of the soil. The field then is left to fallow, until a new growth of trees appears, and eventually it is farmed again.

Among the Jarai, Halang, Rengao, Sedang, and Hroy, the work of preparing the fields for farming usually begins in January or February. Men perform the heavier tasks such as felling trees (large trees normally are left standing) while women and children cut the brush. When the wood has dried, it is gathered together and burned. The larger logs are set ablaze, and the fires are controlled as much as possible. When the rains begin, normally in mid-April or early May, the crops are planted; the men make holes in the ground with dibble sticks while the women follow up to plant the seeds.

The staple crop is upland dry rice, and several varieties with varying maturity periods (usually three to six months) are planted by all of the groups. Also, maize is cultivated in the swiddens as are a number of secondary crops. These include manioc (a major crop in the Phu-Yen Province NLF food production area), sugarcane, bananas, pineapples, eggplant, onions, yams, cabbage, chili peppers, and various kinds of tuber plants. Papaya trees are planted around the edge of the swidden. Many of these same crops are grown in kitchen gardens located in the villages, and the gardens may also contain tobacco, green leafy vegetables, and lemon grass. In some villages, coconut and mango trees are grown. Small huts are constructed near the swiddens so the young men can guard the fields against marauding animals during the growing season.

(b) Results of Interviews

Most informants report having seen the herbicide spraying and give accurate descriptions of the aircraft. From the interviews it appeared the forest or sometimes the swiddens, not the villages, were the targets although spray sometimes drifted into the villages.

A difficult area of inquiry concerned possible deaths due to the herbicides. Sickness and death are common occurrences in Highland villages, and infant mortality is particularly high. In addition, NLF/DRVN propaganda about the harmful effects of the sprayed chemicals, which began in 1962, stressed the fact that human beings--especially children--might fall ill and die if exposed; and both the RVN and NLF/DRVN charged that water and food supplies were being poisoned by the opposing side in order to kill the inhabitants.

The interview subjects consistently reported that illness occurred among people who lived in or near the sprayed areas. The most common symptoms reported were abdominal pains and diarrhea, with vomiting, respiratory symptoms and rashes also frequently reported (Table VII B-11). Some respondents said that there were unusually high numbers of deaths, particularly among children following the spraying.

Most respondents reported widespread deaths among their domestic animals following the spraying, particularly chickens and pigs. Some respondents reported villagers found dead wild animals, particularly wild boars, in the forest after spraying. Responses concerning effects on aquatic life were more variable than those on humans or other animals. Dead fish seen floating in the stream near Long Djon (Location I.1) may have been due to herbicides or they may have been killed by the many soldiers in the area who frequently threw grenades in the streams to kill fish. The Plei Ro-O respondent also reported a great many dead fish in streams following spraying. The fish appeared swollen, and villagers who ate them got diarrhea. Plei Ngol Drong (Location V.1) and Polei Krong respondents (Locations III.1 and III.2) reported similar effects in dead fish following spraying. The latter also noted the gills of some of the dead fish were blackened or reddish in color.

The respondents were consistent in reporting effects of herbicide on plants: over a period of weeks following the spray, plants wilted and died. Where the spray fell on swiddens, the crops died; where it drifted into gardens, the crops wilted. Rice which was not killed outright produced no grain. Fruit trees died, or failed to produce edible fruit. Some villagers reported eating parts of affected plants, after which they got diarrhea. Others decided not to eat any of the sprayed plants. The spraying was reported to have resulted in serious food shortages for the villagers and also for the NLF in some areas. Some villagers reported that big trees survived after losing all their leaves, others reported the big trees had died, and many had been cut for firewood.

Responses of the villagers concerning long-range effects in sprayed areas varied. The Hanoi-trained agricultural engineer reported he believed effects on people and on plants would be only temporary. He believed that one of the types of herbicides being used broke down in the soil and actually increased soil fertility. Some villagers felt they could plant again in the affected areas, but most apparently decided to relocate their fields into unsprayed areas. Some reported persistent effects they believed to be due to herbicides more than a year after the spraying.

Table VII B-11. Illness Perceived by Highlanders Following Herbicide Spraying

Location	Symptoms	People Affected, Deaths
I.1 Long Djon	Abdominal pains, diarrhea, nasal irritation, coughs lasting more than a month	More children than adults were affected "many children died"
I.2 Dak Rosa	Abdominal pains, diarrhea, skin rashes looking like insect bites following contact with sprayed vegetation	Several children died; "unusual number" of still-births among exposed mothers
I.3 Dak Tang	Diarrhea, cramps, skin rashes, fevers	Many children became ill, an estimated 30 died
I.4 Plei Ro-O	Diarrhea, cramps, rashes, fever, coughing blood	Thirty-eight children reported to have died as a result of eating sprayed crops
II.3 Dak Siang	Diarrhea and abdominal pains after drinking water from stream in sprayed area, dizzyness and vomiting after eating bamboo shoots from sprayed area	Some children died after drinking water from sprayed area
II.1,2 Polei Krong	Diarrhea, cramps, fever, rash looking like burns with small blisters over red areas	Higher than usual number of children died after spraying
IV.1 Plei Kleng	Diarrhea, vomiting, fever within one day of spraying	About 40 adults and children died with these symptoms
IV.2 Plei Jar Tum	Diarrhea, vomiting, fever	Four children and one adult died
V.1 Plei Ngol-Drong	Abdominal pain, diarrhea, vomiting, skin rash	Some people died two days after spraying; rash resembled chicken pox
VI. Kontum-Phu Yen Border	Abdominal pain, diarrhea after eating manioc harvested after spray, with inadequate cleaning	Illness only among those not following instructions given to agricultural engineer in Hanoi; no deaths

(c) Summary and Conclusions

The reports of serious deleterious consequences of herbicide spraying on humans, animals, and plants are internally consistent. At a minimum, they indicate an association in the minds of the Highlanders between the use of herbicides and harmful effects to themselves, their animals and plants, and their environment. Reports of human illness following spraying are so striking it is difficult to dismiss them as simply the effects of propaganda, high normal death rates, or faulty understanding of cause and effect.

C. Study of a Mangrove Forest Community in Relation to Herbicide Effects

The Committee wanted to study the direct and indirect effects of herbicides as they affected human communities. An ideal research design would be a coordinated interdisciplinary study *in situ* of a sample of communities representing major land-use types, in order to describe the impact of herbicide spraying on both the natural environment and the human population. We were able to make a partial study combining observations on medical-ecological, botanical, soil, fisheries and socio-economic aspects of human communities only in one settlement in the Rung Sat mangrove area, Tran-Hung-Dao Hamlet in the north central portion of the Rung Sat Special Zone. The location of this settlement is shown in Fig. IV C-5 (Site No. 6).

Of all the ecosystems affected by herbicides, the mangrove forest had the most extensive and persistent damage (see Section IV C). Large blocks have been virtually denuded of mangrove trees. Under these circumstances of undeniable major environmental impact it was appropriate to study effects on human communities of massive use of herbicides, even though the mangrove forest comprises only about 1.7 percent of the total land area of SVN. Recent data on the population of the Gia-Dinh Province portion of the Rung Sat and of Tran-Hung-Dao Hamlet are given in Table VII C-1.

Table VII C-1. Population of the Gia-Dinh Province Portion of the Rung Sat, 31 December 1972

District	Total	Permanent	Temporary
Quang Xuyen	17,097	15,301	1,796
Can Gio	10,350	10,350	0
Rung Sat Total	27,447	25,651	1,796
Tran-Hung-Dao Hamlet (Quang Xuyen District, An Thoi Dong Village)	1,573	1,242	331

Source: HES/70 VILLAGE/HAMLET GAZETTEER as of 31 Dec 72, Report Number R7223.00.0, Hamlet Evaluation System, Run Date 21 Jan 73, MACV-CORDS, Operations and Analysis Division, Village Sequence, pp. 398-399.

Research techniques included an examination of records of herbicide spray missions, and comparison of a series of aerial photos taken from 1957 in the pre-defoliation period to 1973, over two years after defoliation was stopped, to reconstruct patterns of environmental change associated with herbicides. A medical-ecological study was undertaken to determine the existence of malaria and the probable insect vectors responsible for its transmission (Section VII A[3]). About 25 residents were interviewed, some through an interpreter and others in English, to determine community history and economic patterns, and to solicit their recollections of the impact of herbicides on community residents and environment. A small number of samples of water, soil, vegetation, firewood, fish, rice, crustacean and sugarcane specimens were collected for analysis of herbicide residues (see below). The estuarian study reported in Section IV C-6 included collections in the immediate vicinity of Tran-Hung-Dao.

Herbicide operations in the Rung Sat apparently began in 1964 with missions along major channels. Similar missions were carried out in 1965. In 1966 and thereafter spraying included inland portions of the Rung Sat as well, so that a large proportion of the entire mangrove forest area had been sprayed when fixed-wing aerial defoliation was concluded in 1970 (see Figs. IV C-6 and IV C-7). There were three recorded spray projects in 1964 and 1965, and from 1966 through 1969 there were approximately 29 missions (18 of Agent Orange, 10 Agent White, and one Agent Blue) with centerlines passing within one kilometer of the center of the community.

Some time prior to 1957 a fort had been built on the confluence of the Tac Ong Nghia and the main shipping channel to Saigon. The area was one of sparse, impermanent human population. It was a dense mangrove forest, apparently managed for sustained cutting of firewood, and probably also used for fishing. Aside from the military camp there was no permanent settlement nearer than Quang Xuyen, on the Nha Be River, about 5 km to the west.

By 1965 the fort had been abandoned, and there was a strip of killed vegetation along the main shipping channel and other major water routes. By 1967, a new, larger fort had been built, extensive herbicide operations were being carried out, inland as well as along the water courses, and civilian settlement was gathering around the fort. The civilians came primarily from Long An and Kien Hoa provinces, both "pushed" by the urgings of military and civilian officials and "pulled" by the availability of resources and the relative security available at Tran-Hung-Dao. At first they gathered wood and fished. As the dead wood readily available within safe and easy commuting distance of the fort was exhausted, more and more of the people turned to fishing, and to farming which began in 1969. Defoliated areas inland and to the north of the settlement were cleared of debris, watered by the flood of the river during the rainy season, and planted to rice.

The community in February 1973 was composed of about 2,000 Vietnamese civilian residents in the main part of the settlement, a military camp with 65 families of dependents, and about 30 Nung refugees living about 1 km from the main settlement. Hamlet Evaluation System population figures for 31 December 1972 were 1,242 permanent and 331 temporary residents (Table III C-1).

The present economy of the hamlet is best described as marginal, dependent on an insecure and in some aspects vanishing resource base. By February 1973 about 60 percent of the civilian households supported themselves primarily by fishing, 10 percent by farming, and 30 percent by wood gathering. The hamlet is not self-sufficient in rice production, and rice and other food products, as well as drinking water, must be brought in. Firewood and surplus shrimp and fish are sold primarily to the Saigon market; the Nung refugees are farmers and diggers of "Peanut worms" (Sipunculids) which they eat and sell in Cholon.

The firewood is not regenerating nearly fast enough to replace the amount collected. The woodcutters have been reduced to digging up stumps in areas where all the above ground wood has already been cut. Thick regrowth of mangrove trees is found here only on some river banks, not in the interior, which is largely covered with Paspalum grass and scattered shrubby vegetation. The cost of gathering wood (in terms of time and fuel for transport, and also risk of attack) is increasing.

Fish yields are reported to be declining rapidly. Some of the residents attribute it to the great increase in numbers of fishermen within the area, including temporary residents who come regularly for periods of two weeks or more from Kien Hoa or Long An provinces. At this point it is probably impossible to determine whether the herbicides had any direct effect on killing the fish or reducing their ability to breed or to feed themselves. The increase of fishing pressure is undeniable, and the evidence of decline in the fish population (from measures of catch per unit effort and from fish seining studies) seem consistent (Section IV C-6 and Table IV C-4).

Farming is being done by primitive techniques in an area of high salinity and "alum," with an unsure fresh water supply. The development of farmland has been slow because undecayed stumps remaining in the soil must be dug out. The farmers cannot afford draft animals or tractors for plowing. To date they have left the soil untilled, or have hoed their rice fields by hand. They lack the capital or technical knowledge to improve their tillage techniques or substitute other, more suitable crops. Farmers are consistent in reporting declining yields. Some attribute this to inadequate fertilizer; some to inadequate tillage or hardening of the soil; others believe they lost a very large proportion of their crops to rats which they report are present in increasing numbers in the debris of dead and decaying mangrove trees and the grasses which have grown up in the past few years.

Examination of the area in 1973 showed that except for some river banks almost all trees had been replaced by grassy or brushy vegetation, and some areas had been cleared for rice fields. There are fowl and swine in the village, but no fruit trees, and only a few kitchen gardens or chili peppers growing in pots, at least during the dry season when the hamlet was observed. Numerous rats were observed in the hamlet, but because of security considerations it was impossible to trap for rats in the fields (Section VII A-3).

Observations described in Section VII A[3] support the hypothesis that defoliation has produced an environment favorable to the reproduction of malaria-bearing mosquitoes, and that these mosquitoes are now transmitting malaria in an area where it was probably previously absent.

Despite their economic hardships, the lack of water (which they must either buy or receive from the weekly visit of the RVN Navy waterboat), and the apparent limits on their economic future, many of those interviewed indicated they wanted to stay in the community, which at least gives them free access to claim land if they clear and develop it themselves. Many have no land to return to, or fear to return to their homes which they believe to be unsafe.

Those interviewed had a range of opinions regarding the effects of the herbicides on humans, on domestic livestock, and on the fish and crustaceans. Some indicated they had been directly exposed, had suffered nausea or skin irritation or had their hair fall out. Some believed that children had died as a result of herbicide exposure; others said they had suffered no ill effects, and though they recognized that children had died, they believed the deaths (which took place several months after the spray runs passed over the hamlet) were due to malaria or some other cause. Some believed that all fowl exposed to the chemicals became sick and died, and that pigs (sheltered in their pens from direct exposure) became ill but did not die; others believed that no chickens had died as a result of the spray. Some said they had seen the water white with dead fish after the spray and that the fish and shrimp catch had declined ever since, others said they believed the chemicals had no effect on fish or shrimp. Many believe defoliation has made it possible for them to live in the mangrove forest, both by making the area untenable for the NLF forces, and by clearing vegetation from fields which can now be used for growing rice.

Picloram at 0.01 to 0.05 ppm was found in some soil samples from Tran-Hung-Dao. This is in agreement with similar findings in other defoliated areas of the Rung Sat (see Section V A). No 2,4,5-T was found in soil at the sensitivity limit of the method used (<0.02 to <0.0068 ppm). Neither picloram, nor 2,4,5-T and 2,4-D could be detected in rice grain, vegetation (grass, mangrove branches, rice straw), shellfish and fish, and a peanut worm (Sipunculid). Arsenic levels in rice grain, fish and shellfish, the peanut worm, water from a rice field and surface water from the river were well within known arsenic ranges for plants, marine organisms and water. On the basis of the small number of samples we have, there is no evidence that the people of Tran-Hung-Dao ingest herbicides in any substantial quantities, nor arsenic at levels higher than generally found in food and water.[a]

Summary and Conclusions

Tran Hung Dao is a community in an area which was probably sprayed as heavily as any part of SVN. The natural environment (mangrove forest) is representative of only 1.7 percent of the total land area of the country. Tran Hung Dao hamlet is different from some other mangrove forest communities because it has a large number of resettled inhabitants and a sizeable

[a] Analyses for TCDD in fish and shellfish samples from this site have not been completed.

military post with family dependents, but in neither of these respects is it unique in the Rung Sat, and conditions found in Tran Hung Dao appear to represent changes which will be found in other heavily defoliated mangrove areas.

Human settlement and use of resources has become more concentrated and more permanent in places where physical security has been increased by a combination of herbicide applications and military presence. Associated with the wartime changes in settlement patterns to which the herbicides have contributed, there have been a series of technological and economical changes, including use of motorized boats which have made possible a more intensive and extensive exploitation of the forest, fish, and shellfish. Land clearing, assisted in part by defoliation, and the gathering of dead mangrove trees for fuel has in some places been followed by the introduction of wet rice farming. With the present levels of population density and technological and capital investment, returns of all these activities are declining.

Defoliation in the Rung Sat continues to have profound effects on relationships between man and the environment. In the absence of evidence regarding the allegations concerning toxicity and teratogenicity, the major conclusions are: (1) Chemical analyses, as well as the growing of rice, suggest the soil of this area does not contain herbicide residues nor to have undergone other changes which would inhibit plant growth. The slow regrowth of mangrove forest species may be due to lack of sufficient seed sources or changed micro-environment following destruction of most vegetation (compare Sections IV C and V A); (2) ecological changes are in general such as to increase economic instability; (3) the changes in the environment are such as to increase the probability of important harmful diseases. These changes are liable to persist either until there are major alterations in the patterns of human occupation and use of the area, or until the mangrove vegetation is restored.

STATEMENTS OF EXCEPTION

Translated from the French.

Universite de Saigon
Faculte des Sciences
Telephone: 21,096 - Boite Postale: A-2 Saigon
Departement de Botanique

Prof. Pham-hoang Ho

Saigon, December 3, 1973

Professor Anton Lang
Director, MSU/AEC Plant Research
Laboratory
Michigan State University
East Lansing, Michigan 48824

Dear Professor Anton Lang,

I would like to apologize for my being late at the last (November 1973) meeting in Washington. The long formalities necessary to leave the country are responsible.

However, I do not think the results would have been much different, even if I had been on time. It is a pity that the committee lost four to five months more to restudy the problem of the damages in forests; as for myself, I have regretted waiting this length of time to confirm what I wrote to you on 6/21/73, and that at your request I gave my approval not to distribute to the members of the committee. The results of the new (?) study appear to be identical to the ones proposed in June; because they are now better written, in more refined shades, more toned down, more skillful, does not mean that I have to accept them.

I do not speak of the figures concerning the extent of the defoliated areas. We estimate that the non-recorded represent defoliated areas about 15 percent of the total area.

What I would like to speak to you about here concerns the methodology used to calculate the amount of the damages, or more precisely, the material and the methods used.

Material Used

1. The report draft has specified that the committee has chosen a certain number of sites necessary for a good sampling of defoliated forests. But for reasons of security and convenience we have had to adopt other itineraries (p. 30).

We have used a base-line material that we have accepted but not chosen.

2. In addition, the quality of the transparencies, or at least those which I was able to study in Seattle, leave much to be desired - whether because of insufficient sharpness, or because the exposure (time of exposure at the time of shooting or processing?) is not correct (in most instances overexposure), for example, the roll S29 going through the region of Tâyninh, Thiênngôn. The excellent photographs as the roll N16, B8-4 do not represent the majority.

On overexposed transparencies it is already very difficult to count the dead trees because of the absence of contrast: the background becomes lighter than the trunk of the dead trees. It would be impossible to count the poles. In effect, these photographs represent the forest at 1:5,000; a tree trunk of 45 cm or 450 mm diameter is represented thereon by a line 0.09 mm wide, visible if the photograph is sufficiently contrasted. But if the tree is represented by a covered pole it would be represented by a point of 0.09 mm diameter; this point has to be very bright to be easily recognized.

In addition, if the region has been subjected to brush fires, the trunk of a tree may be more or less charred, more difficult to see on the photo; the poles would in this case become practically indiscernible even in stereocopy. The same holds true for the kines, the surviving epiphytes.

3. I have read in the report that the Committee has chosen Tâyninh as study site (XT and YT quadrangles).

I do not know if the study was made with roll N14. As I had occasion to remark in Seattle this roll is not a good sample for several reasons:

- it passes through a region where there are many recent rays (swidden agriculture). It is in no way representative of the forest.

- in the counting, quadrats were not discarded in which there are rivers. Apart from the fact that there are no trees on the rivers, there are along the banks often thickets of bamboo with very few or no trees.

- the roll passes through areas (068) where there are blockhouses (abandoned); around the blockhouses there is a large bare area. Do we consider these areas as a primary prairie or a zone where there are no dead trees?

Methodology

1. Coincidence of the co-ordinates of defoliation operations with those of the damaged forests.

The problem of knowing whether a defoliation swath reported by the pilot and recorded, exactly matches with the one where the defoliants really come into contact with the forest. This problem does not exist when we deal with the overall estimation of the damages. But it exists when one wants to study the influence of the number of operations on the extent of the damages. Often these strips are close together, criss-crossed.

Allow me to believe that in the detail the coordinates given by the HERBS tape do not always correspond to reality. One can admit navigation errors by the pilot; a deviation of a few hundred meters for a large plane is--I think--normal. In addition, there is the drift of the droplets of the herbicide due to wind. The damages to the Hevea plantations, to the teak plantation at Dinhquán, to fruit tree plantations were often due to these causes. In addition, one can also see it on the photographs. For example:

Photo 037 (N16): I counted outside of the swath of defoliation indicated, quadrats (1.5 ha) where there are 7 to 16 dead trees.

Photo 090 (N16): In places where the HERBS tape shows one operation, I counted per quadrat of 1.5 ha 18, 8 to 9 dead trees, when nearby, where 3 operations are indicated, I counted only 8 dead trees.

Photo 0135: In the stretch where the forest is totally decimated, one operation is indicated.

Photo 0143: In the quadrats 134, 133, I counted respectively 11 and 10 dead trees; these quadrats are outside of the swath of defoliation recorded.

The same comments for photographs 0753, 1552....

With all this, allow me not to believe the assertion on p. 34: "The cleared strips coincide geographically with areas where four herbicide missions were flown...." Either the co-ordinates of the HERBS tape are not always the biological co-ordinates, or many times 2 sprays are sufficent to kill all the trees.

All the more reason, it is impossible for me to believe that we can write (p. 35): "the forest was essentially intact after the first three herbicide exposures."

2. I think that for the study of each quadrat, one should not base himself only on the vegetation map of Rollet, but also obligatorily on photographs taken before the defoliation, for example the aerial coverage of 1948.

This makes it possible to not classify a forest which is actually totally destroyed in the category "savanna". I remember that you yourself--like the majority of the members of the Committee--have never believed in the existence of of the areas where the defoliation has destroyed all the trees. At the time of the July meeting, nobody believed me when I spoke of the strips where the forest is totally destroyed by the defoliation. I even showed photographs (unfortunately, in black and white). In the report draft presented in July, it was never mentioned.

In this way, we have eliminated the areas most seriously damaged. Yet these stretches are easily visible from satellites (see infra-red photograph of ERTS I, for example).

When I have been at Seattle, and particularly at the Geographic Department in Washington, for each photograph, I had to look for each photo exactly what was there before the defoliation. It takes longer, but it is more accurate.

3. In Seattle, I brought up the problem of the poles. In my letter of June 21, 1973 I explained it again to you.

Many dead trees appear in 1973--even in 1972, if I remember properly--in the form of trunks without branches (crowns) which we have called by the term poles. Even in the Mangrove, if you remember well, in the maritime region of

Rùng-sát where we were in December 1972, were many poles, too. Along the Route Nationale from Saigon to Phantiết, it is the same.

A great majority of the errors committed in the estimation of the damages derive from these poles:

a. In the first study, these poles were not counted. Dean Bethel himself recognized this fact when I was in Seattle.

Now, these poles are difficult to count, and even if one succeeds, it is with a great margin of error:

- photographed vertically from above, they are represented by a whitish dot of 0.09 mm diameter (for a tree of commercial value with a diameter of 0.45 m). One can identify them with certainty only with a special stereoscope for these large photographs. I did not find one in Seattle. In Seattle, there is a small stereoscope; one can examine these photographs with this small stereoscope provided that the photographs are cut to bring them closer. How many have been cut?

- how to distinguish a dot of 0.09 mm that is counted, from a dot of 0.08 mm that is not counted; corresponding to trees without commercial value, and this with the rolls of photographs without contrast, without sufficient sharpness, or overexposed?

- when the photographs are taken in the morning, with the sun at an angle casting long shadows, the poles are easier to detect if the ground is even, constituted of a savanna for example. This is the case in the strip where the forest is totally destroyed.

But where there still is a shrubby or arborescent layer, the shadows are difficult if not impossible to detect. The photographs 766, 767, 768, and 769 are particularly instructive: one can see projected on the rivers shadows of poles which are themselves invisible!

My observations in the Corypha forest (Nationale Highway from Saigon to Phanthiết) and in the Mangrove lead me to believe that there are now as many if not more poles than dead trees retaining their branches. The study of the photographs in Washington and Seattle confirmed this for me.

Here are some figures taken at random from my notes (per quadrat of 1.5 ha):

Photograph	With Branches	Poles
730	10	7
760	0	40
706	1	3
	6	6
		1
		1
		8
1537		16-18
1553	5	20-25

In many areas where the forest is totally destroyed, there are only poles and no trees with branches. For example, on roll B7.

b. These bare areas bring up other particularly important remarks.

The examination of the photos taken before the defoliation shows that the region was covered by a beautiful forest. On the areas now bare, or more precisely covered by a savanna, I counted for example (photographs 1552-3-4) 10 to 41 poles per quadrat of 1.5 ha.

This does not mean that the primitive forest had only from 10 to 41 trees per 1.5 ha. In other words, even counting the poles correctly--which I doubt--the estimation was made strongly--very strongly--with a lack of judgment.

This therefore makes it already possible to refute the assertion (bottom of page 14) "complete destruction by fire or decay--although such complete disappearance of merchantable size trees in the period in question is unlikely". That complete destruction of the trunks of dead trees happens only in bare areas is highly unlikely!

These bare areas alternate with ones where the forest persists but is strongly damaged. In counting the number of trees alive and dead, one can still get an idea of the trees which disappeared because the number obtained is too small for the normal number of trees of the forest, even secondary.

X

X X

Could I be impassioned or do I have a prejudice in this question? I hope that you know me enough after more than one year of collaboration to not believe it. As of now, I have not written or published anything on the defoliation in Vietnam. As a Vietnamese, I am wrong. But as a scientist, I have liked to have more observations, more studies, to have a more exact idea, free from preconceived ideas on the problem. I thank the Committee for having permitted me to do this.

But conversely, could one say that the portion of this report draft concerning the damages in the forest is impartial? I doubt it strongly. And it seems to me from the beginning, the Committee took--for this portion--an incomprehensible attitude of taking a view opposite to the ideas of some persons.

You said in the introductory part that political conclusions must be avoided. But would it be an apolitical attitude which consists of doing exactly the opposite of what others, whom you judge to be extremists, did?

When reading this part of the Report one cannot help but think of two things. First, the tone used is more one of justifying oneself than that of a scientific work. Next, the effort to minimize the facts is apparent. It is never in my ideas, nor those of Vietnam, to ask for compensation for defoliated forests. The damages--as far as commercial value--belong to the past. But the report is too polarized by this aspect and thus neglects what concerns the biologists, naturalists, environmentalists--namely to understand the biological damages.

In the citations concerning the value of the forests of South Vietnam, only the portions of Rollet's work which suggest a forest of little value are cited. Maurand (1965) who, after all, spent all of his life in Vietnam as a forester and Director of Waters and Forests, has not been cited; nor Barry et al. (1960) who give an idea of the richness of the dense forests in 1960. Not taken into account were the similarities between the forests of South Vietnam and Cambodia, similarities such that Rollet used the same terms to describe them; yet in Cambodia, Rollet gives an average of 200 m^3/ha for the dense forests and 230 m^3/ha for the semi-dense forests; the forests of South Vietnam could be a little richer, being more humid.

This effort resulted in curious numbers that I really do not understand. As on page 30:

volume in cubic meters of all inland forests of SVN:

753.533

If that is the total volume "of merchantable timber", I dare not discuss it further. If that is the estimated volume destroyed by the defoliation, I cannot believe it any more.

Let us take for example just the forests totally destroyed. The committee estimated their area at 53.598 ha.

Using Rollet's figure one obtains

$$200 \text{ m}^3 \times 53,598 = 10,719,600 \text{ m}^3 \text{ destroyed}$$

There are reasons to think that these forests were very rich and dense forests, to deserve to be treated so many times.

The forests defoliated 3 times represent twice as large a surface area. If half of the trees are destroyed, one obtains an analogous number.

So, just for these two types of damaged forests, there is more than $21 \cdot 10^6$ m^3!

As for the forests defoliated one time? In the report draft I have read, I do not have the figure informing on the number of dead trees per hectare for this category. But, judging by the figures concerning the volume of wood of commercial value destroyed (2 to 4% of the figures of Flamm and Westing, i.e., from 10^6 to $2 \cdot 10^6$ m^3) this does not differ much from the ones given in the previous report draft (1.74 m^3 x 301,385, i.e., $0.51 \cdot 10^6$ m^3). I conclude from this that the number of dead trees per hectare has not varied much.

The study of the influence of the number of sprays is difficult when the swaths are close, as in the majority of the cases. One cannot eliminate the drift of the droplets of herbicide.

But some photos (roll N16, very good photographs) permit us to have an idea. These photos are of a region of beautiful forests.

On photograph 090, there are very distinct strips "one spray". On it I counted per square of 1.56 ha:

Quadrat	Number of dead trees
116	17
100	6
140	5-6
139	7-8
139	2

(This is a forest with bamboos, therefore containing less trees).

On photograph 0114:

Quadrat	Number of dead trees
31	12
30	15

Do these dead trees have a diameter DBH greater than 0.45 m? I do not know, but since they belong to the upper story of the forest, I allow myself to believe it.

With such numbers of trees of the upper story dead, the number presented by the committee appears ridiculously low.

In conclusion, as a scientist who--I think--knows Vietnam and who is familiar with the aspects of the defoliation, it appears impossible for me to associate myself with the conclusions of the Committee.

I ask you therefore to kindly present this letter to the Report Review Panel, along with the report draft or, if it is too late, to withdraw my name from the Committee.* If ever this report is translated into Vietnamese, I ask you also to insert the translation of this letter in its entirety.

In more than one year of collaboration, I have admired your kindness and your comprehension, valued the very high competency of the members of the Committee, and enormously benefitted from their knowledge. It was for me one of the greatest honors to work with you. I therefore regret even more not being able to associate my name because of this small part of the work.

Please, dear Professor Anton Lang, believe in my best memories.

/s/ Phạm-hoàng Hộ

Phạm-hoàng Hộ

cc: Professor Richards
Professor Thói

* Since receipt of this letter, Professor Ho has withdrawn his resignation from the Committee, but not his exceptions concerning Section IV B.

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES NATIONAL ACADEMY OF ENGINEERING

2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418

DIVISION OF BIOLOGY AND AGRICULTURE
COMMITTEE ON THE EFFECTS
OF HERBICIDES IN VIETNAM

TELEPHONE: (202) 961-1761

February 4, 1974

Professor Phạm-Hoàng Hộ
Department of Botany
Faculty of Science
227 Công-hòa Street
B.P. A-2
Saigon, Vietnam

Dear Professor Hộ:

This is written in reponse to your letter of 3 December 1973. I have to apologize that this reponse has taken such a long time. I was very busy with various other aspects of finishing the Committee Report and had also to consult a couple of times with Dr. Bethel and Dr. Turnbull concerning certain points in your letter. Permit me also to reiterate in this letter some points which I already made in that of 21 December so that all comments which I would like to make are assembled in one document.

To begin with a number of general points.

I cannot accept your statement that for this part of the study the Committee has taken from the start a partial attitude, namely the opposite view to that of some other persons whom we consider as extremists. In this as in all other parts of the study we have tried to be as unprejudiced as humanly possible, and to use available methods which could be utilized under the circumstances to arrive at objective conclusions. In the estimation of the loss of merchantable timber--chosen because this was the kind of loss where a reasonably reliable quantitative estimate could be made--we used methods which have been used before in non-tropical as well as tropical forests and which have proven to provide results reliable within ca. 10 percent. Because of the problems of this particular study we realize that the reliability is less and use in the latest draft of the report a range, 500,000 to 2,000,000 m^3 which implies a larger error. But we consider it quite impossible that the error is anything like 20 to 100 fold. As to the other authors, our intent was at first not to enter into any discussion of their data. However, the first time our figures were shown to the Report Review Panel we were blamed for disregarding this earlier evidence, and had no choice but to explain why we consider those data entirely wrong. We do not claim to be infallible and may have made mistakes, but this was not because of partiality. If you consider one section of the report as partial this means the whole report is partial. I fully expect that accusations of partiality will be made; I regret profoundly that you are joining in this.

I also regret that you feel the new study consists only in better writing, in softer terms. In fact, this new study involves recounting for merchantable dead trees on more than 33,000 quadrats. The object was to obtain more complete information--whether it changed the preliminary figures or not. Also, much time and effort was spent on 10,000 photos covering the period 1965-70, and on providing specific clarifications to satisfy questions by members of our Committee, primarily your own, and of the Report Review Panel.

Turning now to individual items in your letter:

> -"I do not speak of the figures concerning the extent of the defoliated areas. We estimate that the non-recorded defoliated areas represent about 15 percent of the total area."

We are not clear on this statement. It could mean (i) 15 percent of the area already considered as sprayed, i.e., the actual area is 115 percent of what the Committee used as sprayed area; or (ii) it could mean 15 percent of the whole country, i.e., the Committee's figure of 10 percent for the whole country should be 25 percent.

If (i) is the meaning that it agrees closely with the Committee's estimate that herbicide operations not accounted for in the HERBS records amount to 15 to 17 percent (15 percent of the quantities used, 17 percent of the cumulative area sprayed) of those recorded.

That this amount of sprays is missing is said repeatedly (Section IIIC; Section IVB-3, p. 86) and is discussed in relation to the forest damage study on p. IV-71. It is explained at the latter place that increase in "total country sprayed" and increase in "area sprayed within sample" would both happen as a consequence of over-all increase in area sprayed. Unless there is evidence that the unrecorded spraying was outside MR III or completely missed by the sample, it is fair to assert that the increases in numerator and denominator of the ratio page IV-61, equation (1) would tend to cancel, leaving the ratio unchanged. The limited information concerning pre-August 1965 spraying locates much of it in MR III.

If (ii) is what is meant, this suggests an error of 150 percent. There is nothing in the data available to us to support such an assertion It seems unlikely that this is the meaning intended; if it were so, I would regret very much that we were not alerted to this conclusion before.

"Material Used"

> #1. "The project report has specified that the Committee has chosen a certain number of sites necessary for a good sampling of defoliated forests. But for reasons of security and convenience, we have had to adopt quite different itineraries.--We have used a base-line material which we have accepted but not chosen."

It is true that the sample areas selected had to be reselected. The main points of importance are:

i) The request from the Department of Defense was to arrange the sample points so that they could be flown as a small number of longer lines rather than a large number (over 30) of short flight lines. The reselection was made by the Committee, by making minor shifts in sample location so that sets of points occurred now on the same straight line. These shifts, ranging from 0 to 10 km, were made without regard to the intensity of spraying or degree of effect (the latter unknown to the Committee until the photo flights were made.) The sample areas originally selected and still included in the reselected sample were 23 out of a total of 31, or 74 percent.

ii) The areas selected initially would have resulted in a total sample area of about 40 x 10 kilometers of flight path, or 400 km^2. The reselected areas and lines gave about 7 x 150 or 1050 km^2 or 2.5 times the photo coverage requested originally.

iii) An effect of shifting sample areas could be to increase or decrease the degree of damage or the fraction of any given type of forest included in the sample. An argument against the samples could be made if it were shown that the degree of damage in relation to number of spray applications (based on the HERBS records) was high or low in the sample compared with the spray effect as a whole. No basis for such an assertion has been presented. In fact, the estimates of damage for 2 and more applications, for example, were based on samples that deliberately included some of the most heavily damaged areas.

Altogether, we did not accept samples we had not chosen. The modifications which we made in the original sampling plan were small and are counterbalanced by a larger size of the sample. The sample would be considered entirely satisfactory in forest inventory practice.

> #2. "In addition, the quality of the transparencies, or at least those which I was able to study at Seattle, leaves much to be desired (etc.)"

True. For this reason a careful selection of films was made to give as extensive a sampling as possible and with satisfactory quality. Copies of film seriously lacking in quality (S29) were copied in black and white from the original so that good quality (S59) was obtained. The latter were used in the final sampling.

> -"On overexposed transparencies it is already very difficult to count dead trees because of the absence of contrast; the background becomes lighter than the trunk of the dead trees. It would be impossible to count poles. In effect, these photos represent the forest at 1:5,000; a tree trunk of 45 cm or 450 mm diameter is represented thereon by a line of 0.09 mm wide, visible if the photo has adequate contrast. But if the tree is represented by a covered pole, it is represented by a point of 0.09 mm in diameter; this point has to be very bright to be recognized."

i) The Committee had certainly as much desire to have good data as do yourself.

ii) It is true that in the small portion of film representing area in direct line with the center of the camera field, and vertically below, a pole would appear as a point. But most of the area is not exactly on center; most of the trees are seen with some degree of obliqueness.

iii) Trees (and parts of trees) of a diameter much smaller than 45 cm (e.g., tree branches of a diameter of 10 cm) are clearly visible on film of good quality as selected for the final sample.

iv) Possible errors in dead tree counts, including error in judgement of size are discussed on page IV-67 which should be studied carefully. An important fact is that counting trees too small to be 45 cm in diameter can increase the count (number) of merchantable trees considerably but, since those trees are small, this has only quite a small effect on the volume of merchantable tree. The reverse is true for undercounting merchantable trees.

Reference should also be made to the new non-merchantable inventory (page IV-73) et seq.) and the assessment of damage to non-merchantable volume. As indicated there, the number of trees of 30-45 cm diameter killed by herbicide would be 20-30/ha in some locations. You may question whether these trees are non-merchantable. That they were killed is not being argued. We believe that when you counted dead tree numbers in the range of 20-40 cm many of these were below merchantable size--the only number which we tried to determine at that time.

> -"Moreover if the region had been subjected to brush fires the trunk of a tree may be more or less charred, more difficult to see, and the poles would in this case become practially invisible, even with the aid of a stereoscope. The same holds true for surviving vines and epiphytes."

i) No indication is given as to the extent of such burning. Did it occur often enough to cause a serious error? Generally where brush is extensive, the number of merchantable size trees is small (see Table IVB-4) since most are scattered over areas that had been cleared for agriculture.

ii) As indicated in the discussion of factors that may have affected the estimates of damage (p. IV-63) there is no doubt that dead merchantable trees were included in the count that were not killed by herbicide--compensating to some degree for trees that were killed and then covered or blackened. Again, however, no indication of the amount of the latter has been provided.

> #3. -"I have read in the Report that the Committee has chosen Tayninh as a study site (XT and YT quadrangles).--I do not know if the study was made with roll N14. As I had occasion to remark at Seattle this roll is not a good sample for several reasons:

-"it passes through areas where there are many recent rays (swidden agriculture). It is in no way representative of the forest."

Our samples were chosen to represent all the areas sprayed within the general category "inland forest". The one million hectares so designated include recent swidden that was sprayed - therefore it is sampled. In other samples the amount of such areas is less; the total samples reflect the various vegetation types found within "inland forest" in a manner which would again be considered satisfactory in forest inventory practice.

-"in counting quadrats were not discarded in which there are rivers. Apart from that fact there are no trees along the banks there is often a thicket of bamboos where also few trees are present.

-"the roll passes through areas (068) where there are blockhouses (abandoned); around the blockhouses there is a large bare zone. Are these zones considered as primary prairies or as a zone where there are no dead trees?"

Our non-forest types 6, 7 and 8 are identified in the sample (see page IV-39) and in the results (Table IVB-4) to separate these from forested areas. Rivers are for example in our micro-type No. 7. As expected these areas have very few trees, dead or alive (see also Table IV-60). But they are part of inland forest and therefore cannot be simply disregarded.

"Methodology"

1. Coincidence of the coordinates of defoliation operations with those of the affected forests.

-"Allow me to believe that in the detail the coordinates given by the HERBS tape do not always correspond to reality. One can admit navigation errors by the pilot; a deviation of some hundreds of meters for a large airplane is--I think--normal. In addition, there is the drift of droplets of herbicide due to wind. The damage to Hevea plantations, to the teak plantation at Dinhquán, to tree fruit plantations were often due to these causes."

Agreed; see page IV-71/72 of Report. But herbicide may have also been applied because of these reasons to areas bare of vegetation. Intentional and accidental spraying of crop lands is discussed in several sections of the Report (IIIB, VIIB [1], [2]). Where this occurred in the inland forests (mainly active swidden) that amount should be subtracted from "inland forest area" and added to "cultivated area". But the reverse accident could happen and has happened, i.e., spraying designed for crop destruction has impinged on inland forests (see also Section III B-6).

-"With all this, allow me not to believe the assertion on p. 34: The cleared strips coincide geographically with areas where four herbicide missions were flown."

A study of that whole area established too strong a similarity in pattern of "four spray" applications and pattern of "conspicuous damage" to be dismissed. It is true that some of the severely damaged areas had been both bombed and sprayed.

-"All the more reason, it is impossible for me to believe that we can write (p. 35) 'the forest was essentially intact after the first three herbicide applications'."

In the 1968-69 (1:50,000) photographs the area is undistinguishable from many sprayed areas as visible on black and white photography, namely, it appears as a grey-white swath--within this the trees are visible. In 1972-73 (1:5,000) color photographs the dramatic damage in certain strips is clearly visible. According to spray records, three applications occurred prior to the 1968-69 photographs and one after they were taken. In some parts bomb craters are visible within the dramatically damaged strips.

2. "I think that for the study of each quadrat, one should not base himself only the vegetation map of Rollet but also obligatorily on photographs taken before the defoliation, for example the 1948 aerial photo coverage"

See report. We do not know of 1948 photography. 1958 1:50,000 photographs and some 10,000 prints for the period 1965-70 were used. The prespraying vegetation maps given in the report are derived from the former photographs which are excellent.

3. The problem of poles. Part of this is covered under item #2 of "Methods Used", above. In addition, the following remarks should be made:

i) CEHV counts were made by a combination of monoscopic and stereoscopic observation following a pattern of photo interpretation that is commonly used and that has proved to be accurate in a great many similar studies in the past. This was the subject of a special inquiry when three specialists reviewed our procedures at President Handler's request. We were advised that the team found our procedures to be reasonable and to yield accurate and reproducible results. The procedures consisted essentially of using monoscopic observations when it was found, by checks with stereoscopic observations, that the counts were consistent between the two. This was the case for the large scale counting and typing. For special studies and in doubtful cases stereoscopic observations were used throughout.

ii) Comparison of different observers with the same criterion on the same material was a common quality control procedure used throughout the study. When counts of an observer were consistently higher or lower than of the others they were discarded.

iii) Altogether, we are compelled to say that counting poles, "snags", "climber towers" is a question of photo interpreting skill and we believe that we have coverd this problem in our data gathering, in the range of assessment values presented, and in the narrative in the report.

In the last part of your letter, speaking of the total damage estimate, you say that if this volume is the total for 'merchantable timber' you do not wish to discuss further ("je n'ose plus discuter"); if it is the estimate for the total destruction by defoliation you do not believe in it even more.

Let me emphasize that in the version of the chapter to which your letter refers we were always and explicitly speaking of loss of merchantable timber only. This leads me to say that, in my opinion, the important sources of disagreement are, and have been all the time, two. First, while we were speaking of merchantable timber--this being the type of timber which we felt could be estimated with a reasonable degree of accuracy--yourself and some others had in mind the total standing timber. These are obviously two quite different categories which cannot be interchanged. This problem is discussed on p. IV-49 of the Report. When the difference between these categories is observed, the large volumes you cite for example for Cambodia become much smaller; Rollet considers 15 m^3/ha as a high current merchantable yield. Second, we have followed Rollet's classification of vegetation types in South Vietnam; it seems to me that when you speak of forests you think of undisturbed or little disturbed dense forests. We are aware of the publications of Maurand and of Barry et al., and certainly do not deny that such high quality forests exist in South Vietnam and that they have suffered from herbicide operations. But Rollet's is the only available classification for the entire country, and our objective was to assess the damage in the entire inland forests, not in selected areas of one type or another. The only alternative would be to re-define the term "forest", excluding swidden, bamboo thickets, and some other degraded secondary forests which Rollet in his map includes under "forests." But this would almost mean preparing a forest inventory of South Vietnam, a task beyond the possibilities of this Committee even under much more favorable conditions. As long as the Rollet classification is accepted, however, it is clear that all its "forest types", including bamboo etc., have to be considered. It is, as I am sure you will agree incompatible with the scientific approach to arbitrarily disregard some sample areas or to exclude results we consider well documented by quantitative data, even if these may disagree with qualitative impressions of the forests of South Vietnam. However, I believe that our procedure, accepting Rollet's classification as the only basis available, was the correct one as it covers total damage, in both the good and the poor parts of the forests, and this needs to be known if a comprehensive and efficient rehabilitation program is to be developed. As a matter of fact, we believe, and say so in the Report, that while loss of merchantable timber in the more degraded forest areas is relatively slight, other damage is very serious and calls for rapid action if circumstances should permit it.

Reading the present, final version of the Report you will, I hope, note that we have introduced further modifications, designed to clarify the issues about which you have expressed concern. In particular, we have added estimates of losses of non-merchantable timber--again, please note for the total inland forest area, including all forest types from genuine dense forests to highly degraded secondary ones--even though we have ourselves considerably less confidence in these estimates than those of merchantable timber losses.

Let me conclude by saying that whatever your decision concerning this report, I will always remember with profound respect and gratitude your help and cooperation, given

I am afraid often at detriment to your regular, demanding responsibilities, and I am sure the entire Committee shares this feeling. We know that without your generous assistance we would have accomplished very little.

With best personal regards,

Sincerely yours,

(Signed) Anton Lang

Anton Lang
Chairman

cc Professor P. W. Richards
Professor Le-Van-Thoi

SCHOOL OF PLANT BIOLOGY
UNIVERSITY COLLEGE OF NORTH WALES
MEMORIAL BUILDINGS
BANGOR, CAERNARVONSHIRE

STATEMENT

Though I am in general agreement with the rest of the Report, I wish to express a personal reservation with regard to the section on 'Quantitative Assessment of Herbicide Damage to the Inland Forest'. Earlier estimates of herbicide damage may have been too high, but I am not convinced that the loss of 'merchantable timber' (itself only a small fraction of the total damage to the forest) was not considerably greater than is suggested here. I have been led to this conclusion by my general knowledge of forests in many parts of the tropics, my (admittedly very limited) field experience in SVN, and by such studies as I have been able to make of the air photographs. In my opinion there are two important reasons for the low figures: (1) that the methods used led to a serious underestimate of the number of dead trees in the 1972-73 photography, much of which was of indifferent quality, (2) there was an inadequate appreciation of the post-mortem changes to which trees are subject in humid tropical climates. Because of these changes counts of dead trees and estimates of crown and tree diameters in air photographs taken long after the death of the trees may be very unreliable.

(Signed) Paul W. Richards

Received in the Committee Office, February 4, 1974.

Western Union MAILGRAM

February 8, 1974

Philip Handler, National Academy of Sciences
2101 Constitution Ave
Washington DC 20418

Ordinarily in a joint scientific endeavor that involves several disciplines, each member expects to accept within limits contributions from disciplines not his own without necessarily understanding all the technical procedures and the precise nature of the evidence. When, however, the task is as complex and difficult as the work of our committee and when there is as much controversy as there has been among scientists in given subject matter areas regarding conclusions, then the matter of approving the report as a whole becomes extremely difficult. I have in mind particularly the section on the inland forests and think it not appropriate that I should appear as either approving or disapproving it.

Alexander H. Leighton, M.D.