The Effects of Herbicides in South Vietnam

Part A Summary and Conclusions

NATIONAL ACADEMY OF SCIENCES
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

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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.

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ABBREVIATIONS USED IN THIS REPORT

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

Origin of the Study (Section I)\textsuperscript{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

\textsuperscript{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.

History of Military Use of Herbicides in South Vietnam (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.

The Herbicides Used in the Vietnam War (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

<table>
<thead>
<tr>
<th>Year</th>
<th>1962- Jul 1965</th>
<th>Aug-Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>NA</td>
<td>0.37</td>
</tr>
<tr>
<td>White</td>
<td>NA</td>
<td>0.00</td>
</tr>
<tr>
<td>Blue</td>
<td>NA</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>1.27</td>
<td>0.37</td>
</tr>
</tbody>
</table>

*Not available.

Table II.

Herbicides Used in SVN 1965-1971

<table>
<thead>
<tr>
<th>Agent</th>
<th>Active Chemical Components</th>
<th>Military Application Rate (lb/acre)</th>
<th>Millions of gallons used, Aug. 1965-1971</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange</td>
<td>2,4-D, 2,4,5-T</td>
<td>12.00</td>
<td>11.22</td>
</tr>
<tr>
<td>White</td>
<td>2,4-D, Picloram</td>
<td>6.00, 1.62</td>
<td>5.24</td>
</tr>
<tr>
<td>Blue</td>
<td>Cacodylic acid</td>
<td>9.30</td>
<td>1.12</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>17.58</td>
</tr>
</tbody>
</table>
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 arenesallic 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-p-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.

**TCDD, a Contaminant of 2,4,5-T (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.

**Inventory of the Military Use of Herbicides in South Vietnam (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\(^a\)**

<table>
<thead>
<tr>
<th>Vegetation Type(^b)</th>
<th>Total in SVN in 1953</th>
<th>Number of Times Sprayed Aug. 1965-Mar. 1971</th>
<th>Total Sprayed one or more times</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millions of acres</td>
<td>Millions of acres</td>
<td>Millions of acres Percent</td>
</tr>
<tr>
<td></td>
<td>Percent</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Inland forest</td>
<td>25.91</td>
<td>1.72</td>
<td>0.62</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>7.80</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td>Mangrove forest</td>
<td>.72</td>
<td>0.14</td>
<td>0.07</td>
</tr>
<tr>
<td>Other</td>
<td>7.07</td>
<td>0.31</td>
<td>0.07</td>
</tr>
<tr>
<td>Total</td>
<td>41.50</td>
<td>2.37</td>
<td>0.80</td>
</tr>
</tbody>
</table>

\(^a\)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.

Effects of Herbicides on Soils (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.

Effects of Herbicides on Humans (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.
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.

Psychological Reactions to Herbicides (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 fishingboat. 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 documentation 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 deficiencies 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 sub-units 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."