Ecological Effects of the War in Vietnam

Effects of defoliation, bombing, and other military activities on the ecology of Vietnam are described.

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Wars are always destructive of environments, but never before have the ecological effects of a war been a major issue. For the past several years there has been widespread concern among scientists about the massive use of chemicals for defoliation and crop destruction in Vietnam. Because these chemicals have never before been used in military operations, there are no data upon which to predict the effects of such use. However, J. S. Foster, Director of Defense Research and Engineering, Department of Defense, has stated that the Department of Defense would not use these chemicals if it judged that seriously adverse ecological consequences would occur. The basis upon which this judgment was made is not clear in view of the fact that the report of the Midwest Research Institute (sponsored by the Department of Defense) on the ecological effects of herbicides (*1*) points out that predictions based on civilian uses are not valid. This is because the military application of herbicides in Vietnam is carried out under conditions that are not comparable to the civilian situation.

Recognizing that there were no data on the ecological effects of the military use of herbicides in Vietnam, the Department of State sent F. H. Tschirley, a U.S. Department of Agriculture plant ecologist, to Vietnam in March 1968, to make a 30-day assessment of the ecological effects of defoliation. His report (*2*) indicates that the defoliation program is having a profound effect on plant life in Vietnam. He was, however, unable to get first-hand data on many aspects of the problem, including effects on animal life. Accordingly, the Society for Social Responsibility in Science decided to sponsor a trip in March 1969, with the objective of supplementing Tschirley's observations with those of zoologists. Unfortunately both of these visits have been made in the dry season.

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Sources of Information

We gathered information and impressions from interviews with military personnel involved with both field operations and policy decisions. We traveled by helicopter over areas damaged by B-52 bombing raids, and we flew on spray missions with the C-123 aircraft which have been modified for spray application. We were also able to take a 2-hour, 40-minute (104 kilometers) trip by Navy patrol boat through the Rung Sat Special Zone, an extensive region of mangroves on the Nha Be River, which has been heavily defoliated. The main shipping channel to Saigon passes through the area and widespread defoliation has been used to reduce the incidence of rocket and mortar attacks on vessels coming up the river. We are grateful to the U.S. Embassy, Army, Navy, and Air Force, the Rubber Research Institute of Vietnam, Plantations Michelin, and the many Vietnamese biologists, both in governmental and nongovernmental positions in their country, for their cooperation and hospitality. All information which we requested from the Department of Defense that did not carry a security classification was made available to us.

Because rubber plantations are one of the most important sources of foreign capital in Vietnam and since the rubber tree *Hevea brasiliensis* is particularly susceptible to damage by defoliants, especially 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) (*3*), we interviewed plantation owners concerning defoliation damage. The planters themselves have not carried out systematic studies of the physiological effects of defoliants on rubber trees, but they have been very much interested in estimating their losses. The Rubber Research Institute of Vietnam, a private research corporation, has made careful observations of the nature and extent of damage to rubber trees and has carried out some experiments to find ways of minimizing the loss to defoliants. The data in the files and publications of the Institute, kindly made available to us by the director, Jean-Paul Poliniere, were invaluable to us in learning more about effects of defoliation on rubber trees. Also, during a visit to the research station of the Institute, we were able to observe recent damage to trees by defoliants and to view pictures of trees damaged and killed by previous defoliations. Officials of the Michelin Plantations also provided us with data from their files on the nature and extent of herbicide damage to rubber trees on one of their plantations.

The Faculty of Science, University of Saigon, and government agencies concerned with plants and animals, such as Ministries of Fisheries, Forestry, and Agriculture, are staffed with biologists trained primarily in France and the United States. These people are knowledgeable and concerned about the ecological effects of the war in their country. By means of interviews with them we were able to assess their concerns, find out what kinds of studies have been initiated, explore ways of helping them launch future studies, and to gather information they had collected which was relevant to our mission.

Wartime conditions prevented us from making ground observations in heavily defoliated forests, but we were able to discuss damage with B. R. Flamm, Chief, Forestry Branch, U.S. Agency for International Development, Saigon, and to examine photographs he took inside forests receiving one and two applications of defoliants. In addition, one of us (G.H.O.) visited some of the sites in Puerto Rico, which have been used to test defoliants under tropical conditions, in April 1969, for a closer look at vegetation recovery and animal populations.

Because previous work on the effects of defoliation in the field have

dealt almost entirely with direct effects upon plants, we made a special effort to observe animals in all the areas we visited and to ask as many questions as we could about changes in the status of animals. Because our own knowledge was most extensive about birds we learned the most about them, but we did gather some information on other taxa through interviews. Because of the short duration of our visit we were unable to obtain definitive answers to some of the most important questions which have been raised by the American scientific community about the ecological effects of the war, but we feel that the material we gathered forms a significant contribution to continuing efforts to assess the impact of modern warfare upon the environment in which man must live.

Operational Aspects of the Defoliation Program

Inasmuch as it is the widespread use of herbicides in Vietnam that has been of greatest concern to American scientists, we gave top priority to learning about the effects of the defoliation program in Vietnam. Defoliants have been used in Vietnam by the United States since 1962. The program started modestly but increased sharply after 1965 (Table 1). A peak was reached in 1967 followed by a slight reduction of total area sprayed with defoliants in 1968 as a result of the reassignment of equipment for other missions following the Tet Offensive (*4*). The bulk of the spraying is directed against forests and brush, but a significant proportion is directed against cropland in the mountainous parts of the country (*4*). The U.S. military authorities believe the food grown in the mountainous areas is used to feed the forces of the National Liberation Front. They deny using defoliants on rice crops in the delta region. Much of the defoliation is along roads and rivers and around military establishments, and border areas (near Laos and Cambodia) are extensively defoliated. Forested regions north and northwest of Saigon in Tay Ninh, Binh Long, Binh Duong, Phuoc Long, and Long Khanh provinces have been very hard hit. This area contains some of the most valuable timber lands in the country. In most cases, broad forest areas have not been repeatedly defoliated, though possibly 20 to 25 percent of the forests of the country have been sprayed more than once.

Table 1. Estimated area (1 acre = 0.4 hectare) treated with herbicides in Vietnam. Actual area sprayed is not known accurately because some areas are resprayed. Areas are estimated from the number of spray missions flown, the calibrated spray rates and the width of spray swath covered. [From Department of Defense data.]

Year	Defoliation (acres)	Crop destruction (acres)
1962	17,119	717
1963	34,517	297
1964	53,873	10,136
1965	94,726	49,637
1966	775,894	112,678
1967	1,486,446	221,312
1968	1,297,244	87,064

Roadsides and riverbanks are subjected to multiple defoliation at regular intervals.

Officially the defoliation program is a Vietnamese program with the assistance of the United States. The initial request for defoliation may be made by either a district or a province chief with the support of his American advisor. Included in the request must be the claim that the targeted area is under control of the National Liberation Front or of the North Vietnamese. The chief must also pledge to reimburse his people if there is any accidental damage to their crops by wind-blown spray or other causes. The request also must contain a promise to inform people in the target area that it will be sprayed, giving them the reasons for the spraying, and offering them the opportunity to change their allegiances if they so desire. Plans are supposed to be made in advance to handle any refugees which might result from the operation.

This request then goes to the division tactical zone commander and his American advisor, then to the Corps commander and his advisor, and then to the Vietnamese Joint General Staff and its American advisors in Saigon. In Saigon the request is circulated among a broad spectrum of groups dealing with pacification operations, intelligence, psychological warfare, and chemical warfare. Finally, permission must be given by the commanding general and the United States Ambassador to Vietnam.

Despite this formal arrangement, in Vietnam the program is generally considered to be an American one, and military justification of it is always given in terms of the American lives it saves. Moreover, there is evidence that the many precautions specified by the procedures are neglected regularly. For example, aerial reconnaissance of the target area prior to the decision to spray it, is omitted if the schedule is busy, and in enemy-held areas there is often no warning given.

To reduce transfer of herbicides by the wind and to improve the kill on the desired target, the military authorities have established regulations governing conditions under which defoliation may take place. Missions are to be flown only when the temperature is less than 85°F (29.4°C) and the wind is less than 10 knots. This restricts aerial spraying to morning hours, though usually an attempt is made to fly two successive missions each morning.

The defoliants used in Vietnam, the concentrations used, and those used in U.S. civilian operations, and the purposes for which they are best suited are given in Table 2. In the region of Saigon, where wind-blown and gaseous herbicides pose threats to cropland, agent White is now preferred because of its lower volatility and persistence, but in regions where there is little agriculture, Orange is the preferred agent because it is more economical. Presently in Vietnam, Orange constitutes about 50 percent of the total herbicide used, White 35 percent, and Blue 15 percent, the latter being used primarily against mountain rice crops (*4*). Approximate areas where extensive defoliation has been carried out are shown in Fig. 1.

Effects of Defoliants on Trees

It was impossible for us to visit defoliated forests on foot or by means of ground transportation. We, therefore, are unable to add much to what has already been reported on the direct effects of defoliants on forest trees. We can confirm Tschirley's report (*2*) that the trees which are collectively known as mangroves are extremely susceptible to the action of defoliants and that one application at the normal rate employed in Vietnam is sufficient to kill most of the trees. Most of the areas we visited by boat on the Rung Sat Peninsula (Fig. 1) were still completely barren even though some of the areas had been sprayed several years earlier. Only in occasional places was there any regeneration of mangrove trees. We observed no growth of the saltwater fern *Achrosticum aureaum* which often invades mangrove areas.

Mangrove vegetation is floristically simple, the forests in Vietnam being

dominated by *Avicennia marina, A. intermedia, Rhizophora conjugata, Bruguiera parviflora, B. gymnorhiza, Ceriops candoleana,* and *Nipa fruticans,* the latter species also forming dense stands along most rivers in the delta region where they are subject to tidal influence. The normal pattern of vegetation succession in mangrove areas has been reviewed by Tschirley (*2*) who suggests that about 20 years would be required for the reestablishment of the dominant *Rhizophora-Bruguiera* forest. This estimate is based upon the assumption of immediate redistribution of seeds to the defoliated areas and the presence of suitable germination conditions when they arrive. Although our observations were limited to what we could see from the boats with binoculars, there is reason to believe that the timetable may be somewhat longer than this. Possibly conditions for seed germination are not now very good in the defoliated forests. The unusual soil conditions of mangrove forests may result in a failure of the herbicides to be decomposed. If the molecules remain bound to the soil particles they might influence seed germination for a long time. Alternatively, seed dispersal into the areas is difficult because of the large areas in which mature trees have been killed. Many of the areas, as a result of continued soil deposition under the trees, are flooded only at the highest of high tides, and seeds must be transported for long distances from the river channels under very unfavorable conditions. It cannot be excluded that reestablishment of the original forest may be impossible except along the edges of the river channels and backwaters.

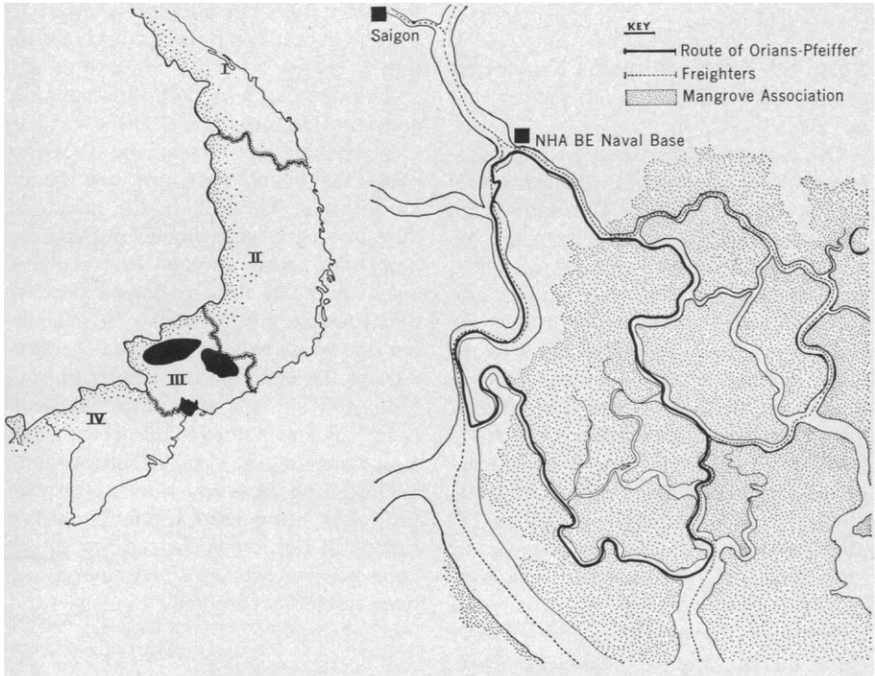


Fig. 1. (Above, left) Approximate areas of massive defoliation in III Corps, as indicated by Chemical Operations, MACV. (Above, right) Map of route through Rung Sat Special Zone. (Below) Defoliated mangrove association in Rung Sat Special Zone.

Military operations in Vietnam provide an opportunity to study the effects of unusually high rates of application of herbicides. For example, before jet pods were installed in the C-123 aircraft, the planes were unable to remain aloft in case of engine trouble. In such a contingency, the crew could jettison the entire contents of the tank (1000 gallons; 3.79 kiloliters), in slightly less than 30 seconds, whereas normal spray time is about 4 minutes. Although such contingencies are said to occur less frequently now, they do continue to happen. On the spray mission which one of us (E.W.P.) accompanied as observer, the spray nozzles of one plane failed to work properly, and the entire tank was unloaded at the end of the target. Because the locations of targets are pinpointed very precisely, and because reports are made of all unusual activities during a spraying mission, it should be possible to keep a record of such occurrences. It is most important that all such incidents be recorded in order to enable biologists, in the future, to investigate the sites of concentrated defoliant applications.

Effects of Defoliation on Upland Forests

Our observations on upland forests that were sprayed directly were limited to aerial reconnaissance. Regrettably we have nothing to add to the published studies about the short-term effect of defoliants on tropical forest trees after single applications of herbicides (*1*, *2*, *5*). The area in northern Long Khanh province that one of us (G.H.O.) observed from the air had been sprayed previously, and many of the trees on the actual target of the

mission already appeared to be dead. Except for the wetter spots which were covered with bamboo, the ground was clearly visible in most areas from the low-flying aircraft. Many areas in War Zones C and D (Fig. 1) have been sprayed more than once, and this multiple spraying is also associated with coverage of wide areas. Vegetative recovery as judged from the air was limited to the growth of bamboo and understory trees rather than to refoliation of the canopy dominants.

Observations of defoliated upland forests were made from the ground by Tschirley (*2*) and Flamm (*6*). They visited defoliated forests near Special Forces camps in Tay Ninh and Binh Long provinces northwest of Saigon, a region of gray podzolic soils. According to these studies, after defoliation, on sites sprayed once, there appears to be a modest kill of canopy trees, but understory seedlings and saplings survive and forest regeneration begins fairly rapidly (Fig. 2). However, on sites that received two sprayings roughly 1 year apart, a heavy kill of all woody plants, including seedlings, is reported. Two or three spray applications may kill approximately 50 percent of commercially valuable timber in such forests. These areas are being invaded by grasses which are resistant to forest defoliants and which may arrest succession by preventing the reestablishment of tree seedlings for a long time. Even if this does not occur, it will take many decades before a mature forest grows. Subtle effects, such as changes in the species composition and forest physiognomy, may persist for much longer than that.

A year after spraying, timber is still in good condition, and could be harvested for commercial use, if equipment and markets are available. However shrapnel will be a serious problem for the Vietnamese lumber industry for many years. Most sawmills report that they lose from 1 to 3 hours each day because shrapnel in the logs severely damages the saw blades. The forestry program is looking for suitable metal detection equipment that might help to reduce this damage.

A variety of herbicides, including picloram, bromacil, isopropylamine, prometone, dicamba, divron, and fenac have been tested for their effects under tropical conditions in Puerto Rico since 1962 (*7*). The plots visited in April 1969 were located at an elevation of 540 meters in the Luquillo Experimental Forest in northeastern Puerto Rico. They had been sprayed in 1965 with a Hiller 12-5 helicopter which delivers the spray over a standard swath 35 feet (10.7 meters) wide. The plots were 60 by 80 feet (18 by 24 meters) separated by buffer zones 20 feet (6 meters) wide and there were three replications, ordered in a randomized block design, with 50-foot (15-meter) buffer zones between the strips. The extent of defoliation had been measured 1 year after treatment, the percentage of defoliation on each tree being estimated visually. Apparently there had been no recent ground visits to the sites because all the trails were overgrown and the boundaries of the plots were almost impossible to find. There has been little interest in the continuing effects of the herbicide treatments. This is unfortunate for some areas received very high rates of herbicide application [27 pounds acid equivalent per acre (30.2 kilograms per hectare)]. Assays of growth rate and germination of cucumbers, made in soils up to 1 year after application of the herbicides, revealed relatively high concentrations of picloram, although this technique does not provide precise quantitative measures.

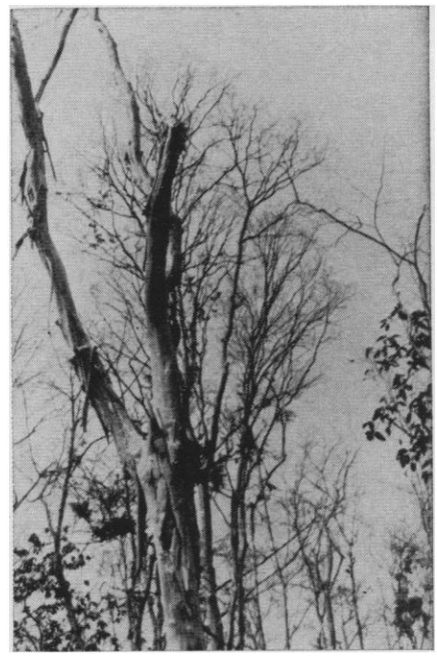


Fig. 2. Defoliated crowns of *Lagerstroemia* and *Pterocarpus* near Tong Le Chon. [Courtesy of Barry D. Flamm]

There is a possible serious source of error in the visual estimates of the speed of refoliation in these Puerto Rican rain forest plots. At the higher rates of herbicide application, it was clear that most of the trees had been either killed or severely damaged. However, these plots had been invaded by vines which climbed the trunks of the dead trees and spread out over the former canopy. On some of the plots nearly all of the greenery above 3 meters was contributed by vines and not by refoliation of the original trees. Nevertheless, a quick visual estimate, particularly if it were made from a helicopter, might be taken to indicate that extensive refoliation of trees had occurred. The vine-choked plots will not return to their former state as rapidly as they might otherwise, because the dead trunks will probably collapse under the weight of the vines in a few years, cre-

Table 2. Chemical composition, rates of application, and uses of military herbicides from data supplied by the U.S. Departments of Defense and Agriculture. One pound per gallon, acid equivalent (AE) equals 114 grams per liter. One pound per acre equals 1.12 kilograms per hectare.

Agent	Composition (%)	Concentration (lb/gal AE)	Rate of application (lb/acre)		Use
			Vietnam	U.S.	
Orange	*n*-Butyl ester 2,4-D 50 *n*-Butyl ester 2,4,5-T 50	4.2 3.7	27	2	General defoliation of forest, brush, and broad-leaved crops
Purple	*n*-Butyl ester 2,4-D 50 *n*-Butyl ester 2,4,5-T 30 Isobutyl ester 2,4,5-T 20	4.2 2.2 1.5			General defoliation agent used interchangeably with agent Orange
White	Triisopropanolamine salt, 2,4-D Triisopropanolamine salt, picloram	2.0 0.54	6 1.5	 0.5–2	Forest defoliation where longer term control is desired
Blue	Sodium cacodylate 27.7 Free cacodylic acid 4.8 Water, sodium chloride balance	3.1	9.3	5–7.5	Rapid short-term defoliation. Good for grass control and use on rice

ating a low, vine-covered mat through which regeneration could be very difficult. We urge that continued studies of vegetation succession on these and other Puerto Rican test plots be undertaken so that the time required to reestablish the original forest and the factors influencing the pattern of succession can be determined.

Some vine invasion was also characteristic of plots receiving lesser amounts of herbicides, but a severe setback in these forests did not appear to have taken place. Seedlings of mahogany, *Swietenia macrophylla*, and Caribbean pine, *Pinus caribaea*, which had been planted in some of the plots a month after defoliation were surviving quite well.

Effects of Defoliants on Animals

Tschirley obtained no direct information on the effects that killing the mangroves had on animal populations, but he cited statistics that the fish catch in the Republic of Vietnam has been increasing. Because many factors influence total fish catch and because most of the fish are caught in regions not directly exposed to defoliation, the significance of these data is unclear. Therefore, we attempted to learn as much as we could about animal populations in the defoliated mangrove forests.

As might be expected, the almost complete killing of all of the vegetation of the mangrove areas by herbicides has had a severe effect upon the animals living there. During our tour of the defoliated areas we did not see a single species of insectivorous or frugivorous bird with the exception of barn swallows, *Hirundo rustica*, which are migrants from the north. Although no data regarding the bird populations in the Rung Sat prior to defoliation exist, our experiences in mangrove areas in tropical America indicate that there should have been large numbers of land birds. For example, in Panama as many species of birds were found in a pure red mangrove (*Rhizophora mangle*) forest as would be expected on the basis of the leaf height profile (density of leaves per unit volume as a function of height of forest) of the stand (*8*), and in a brief census of a similar mangrove forest (primarily *Rhizophora*) in Costa Rica, 44 species of land birds which appeared to be resident and breeding were recorded (*9*). Mangrove areas throughout the tropics are rich in bird species (*10*), many of them restricted to that type of vegetation, and the Southeast Asian mangroves are no exception.

Fish-eating birds seem to have suffered less severely, but even their numbers were much fewer than we expected. The species of birds and the number of individuals per species that we observed during a 2-hour period in the defoliated areas, are: oriental darter (*Anhinga melanogaster*), 2; grey heron (*Ardea cinerea*), 13; large egret (*Egretta alba*), 3; little egret (*E. garzetta*), 12; intermediate egret (*E. intermedia*), 1; javan pond heron (*Ardeola speciosa*, 6; stork (*Leptoptilos* sp.), 2; black-winged kite (*Elanus caeruleus*), 1; osprey (*Pandion haliaetus*), 9; whimbrel (*Numenius phaeopus*), 3; little tern (*Sterna albifrons*), 10; and white-breasted kingfisher (*Halcyon smyrnensis*), 2. All except the kite, which feeds on small mammals, are fish-eating birds. This suggests, as would be expected, that aquatic food chains in the mangroves may have been less severely affected by defoliation than the terrestrial ones. The only other vertebrate we saw in the defoliated areas was a large crocodile *Crocodylus* on the bank of a small channel.

Of all the areas in Vietnam, the mangroves in the delta of the Saigon River have probably been most severely affected by defoliation. The area treated has been very extensive, covering many square kilometers, the vegetation is extremely sensitive to herbicides, and many of the species of animals inhabiting mangroves are restricted to that type of vegetation. These animals are therefore inhabitants of "islands" surrounded by unsuitable habitat and as such are expected to have higher rates of extinction even under normal conditions than species of more continuous habitats (*11*). These same properties make them more susceptible to local and complete extermination by disturbance and destruction of habitat than are species of upland habitats. Long-term studies of the ecology of the Rung Sat should be given a high priority, including investigation of the status of such invertebrates as crustaceans.

Birds were scarce in the heavily defoliated plots in Puerto Rico, but in the more lightly treated areas both species composition and general population density were comparable to that found in untreated areas in the general vicinity. There was not time to conduct a complete census, but it is doubtful whether such studies would be worth while since the plots are so small that they are less than the average size of most bird territories. Therefore, the effects of the tests on bird populations should in any event be mimimum. It is important to remember, however, that results from spraying of very small areas cannot be assumed to apply to extensively treated areas.

Toxicity of Herbicides

The problem of the toxicity of herbicides to animals is not yet resolved. Nearly all studies are short term, and results are contradictory. Some reports (*1*) suggest that at the prevailing concentrations herbicides are not directly toxic to animals, and Tschirley (*2*) states: "There is no evidence to suggest that the herbicides used in Vietnam will cause toxicity problems for man or animals." However, according to Holden (*12*) 2,4-dichlorophenoxyacetic acid (2,4-D) may constitute a potential danger to fish even in normal use. The LD_{50} value for salmonids during a 24-hour exposure to 2,4-D is 0.5 part per million. Thus, a concentration of 4 pounds of active constituent per gallon (458 grams per liter) in a small [10 cubic feet (0.28 cubic meter) per second] stream would expose fish to about 100 times the LD_{50}. It should be recalled that the rate of application of 2,4-D in Vietnam is slightly greater than this. According to Holden, the toxicity of 2,4,5-T is about one-half that of 2,4-D.

Another possible source of toxicity to animals from defoliation is an indirect effect of the activity of 2,4-D in plants. Stahler and Whitehead (*13*) reported that there are several cases of cattle becoming ill or dying after eating certain species of weeds that had been treated with 2,4-D. These authors present data that clearly indicate that sublethal dosages of 2,4-D may markedly affect the metabolism of certain plant species so that toxic quantities of nitrates accumulate in the treated plants. In the animals the nitrates are changed to nitrites which are absorbed into the blood producing methemoglobin which results in oxygen deficiency to the tissues. This condition may cause death or illness resulting in abortion. Leaves of sugar beets that had been treated with 2,4-D were shown to have amounts of nitrate well

above the minimum lethal concentration. A recent statement (*14*) by an American agricultural specialist emphasizes that "Dairy cows should not be grazed on irrigated pasture for seven days after application of 2,4-D at the one-half pound and over rate of application."

To our knowledge there are no studies of the effects of agent Orange on Vietnamese forage plants to determine whether these plants become toxic to animals due to nitrate accumulation following defoliation with Orange. Determination of nitrate concentration in leaves should be made in defoliated and control areas, and the hemoglobins of animals which feed on exposed plants should be studied.

A recent study of the teratogenicity of 2,4-D and 2,4,5-T (*15*) shows that the latter compound is highly teratogenic in rats and mice at dosages that are possible of ingestion by humans in Vietnam.

We uncovered little evidence of direct toxic effects on animals. The Tan Son Nhut air base in Saigon is sprayed by hand with agent Blue several times each year and nonetheless has a serious rat problem. A trapping crew every night puts out 100 snap traps and 30 live traps, baited with bacon. From 3 January 1969 to 19 March 1969, they had trapped 613 rats and 8 viverrids of at least two species. We netted and observed birds on a previously sprayed brushy area near Bien Hoa on two different mornings and found birds very common. We saw much territorial defense and singing as would be expected at the end of the dry season in the tropics.

We did receive one report of many sick and dying birds and mammals in forests following defoliation and two reports of death of large numbers of small pigs near Saigon, but were unable to follow up either report. The Ministry of Agriculture has received no bona fide claims of animal damage from defoliants. Nevertheless, we must not forget that habitat destruction, which defoliation regularly accomplishes, is in most cases the equivalent of death for animals. The widespread view that animals can move to other nearby areas is untenable because recent ecological evidence suggests that tropical forests hold the maximum number of individuals of most species that the resources will support. Reduction of forest habitats will decrease the populations of forest animals by an equivalent amount. Nor is it true that forest species can live successfully in the greatly modified conditions which prevail in even partially defoliated forests. Species characteristic of successional stages will, of course, be expected to move into the disturbed areas, but even they may have to wait until the basic food resources, such as insects and fruit, have built up again, and we do not know how long this will take.

A phenomenon that should be investigated immediately is a widespread sickness which appears at the beginning of the rainy season in commercially important freshwater fishes. The symptoms are many small, round, dark spots in the muscles. The taste of the fish is also adversely affected. Poor people continue to eat the fish even though they are diseased. This disease has always been characteristic of that time of the year in Vietnam, but the director of the Institute of Fisheries has received reports which suggest that the incidence is now higher than before. Conditions in the shallow water of the fields are ideal for concentration of herbicides. The Vietnamese fisheries people, who are qualified and presently have greater mobility in the country than Americans, are in a position to initiate such studies now. The Minister has already circulated a letter among his representatives in the provinces asking for any information they may have, and we agreed to help formulate a more detailed questionnaire for future circulation.

Some insight into the possible harmful effects of the herbicides now in use in Vietnam may be gained by consulting the labels which give directions for their uses. Dow Chemical Co., makers of agents Orange and White, warn that these chemicals should be kept out of reach of children and animals. The label on agent White states: "Do not allow material to contaminate water used for irrigation, drinking, or other domestic purposes." Dow Chemical Co. also recommends that no grazing be allowed on treated areas for 2 years after treatment and that some broadleafed crops may show damage 3 years after application.

Ansul Chemical Co., makers of agent Blue, state that when an individual is exposed (to cacodylic acid) daily for extended periods, the inspection of skin sensitivity should be supplemented by monthly urinalysis for arsenic. Symptoms of acute poisoning from cacodylic acid are headache, vomiting, diarrhea, dizziness, stupor convulsions, general paralysis, and death. The dosage required to cause these symptoms may be as little as one ounce (28 grams) of cacodylic acid per human adult.

Effects of Defoliants on Rubber Culture

Most studies of the effects of defoliants on forest trees have been confined to observation of the percentage of defoliation after relatively short intervals following single applications of herbicides. Studies of the effects of defoliation on rubber trees have been initiated by the Rubber Research Institute of Malaya and by the Rubber Research Institute of Vietnam because of the economic importance of rubber trees to Vietnam and because of the widespread damage to plantations from military spraying. Although these studies contain the best available data, they have been limited by the shortage of funds and difficulties of field work in a country during wartime.

Damage to rubber trees in Vietnam has been extensive. During 1967–68, the Institute staff visited over 200 different plantations in the provinces of Bien Hoa, Binh Duong, Gia Dinh, Hau Nghia, Long Khanh, Phuoc Tuy, Tay Ninh, and Binh Long. (This covers most of the area between the rice-growing areas of the Saigon and Mekong River deltas and the mountainous central part of the country.) On this extensive area of approximately 130 by 40 kilometers, all plantations reported damage by defoliants. More than 40,000 hectares planted with rubber trees were defoliated at least to the extent of 10 percent. It is difficult to estimate the total amount of damage resulting from defoliation. Plantation owners might possibly submit exaggerated claims, but there is no doubt that the damage has been considerable. For example, Plantation de Dautieng of the Michelin Company has been affected by defoliants three times since 1965. In all cases, the defoliant has not been applied directly to the rubber trees, but has been carried by the wind from applications in the general area. No trees were killed, but, by measuring the drop in latex production due to stoppage of tapping, decreased yield of lightly damaged trees, and costs of cutting and trimming back partially killed trees, the company estimates that the damage amounted to $27,835 in 1965, $37,479 in 1966, and $27,844 in 1967. The

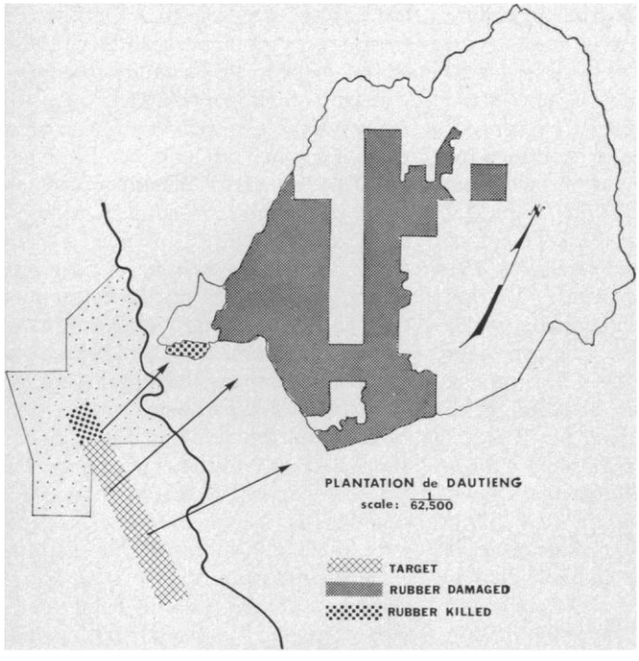
areas of spraying, direction of the wind, and areas of the plantation affected are shown in Figs. 3 to 5.

The yield of rubber per hectare is decreasing. In 1960, rubber plantations in Vietnam yielded 1066 kilograms of dry rubber per hectare (on plantations of more than 25 hectares). In 1967, the yield had dropped to 793 kilograms per hectare. In contrast, in Malaysia the yield in 1960 was 758 kilograms of dry rubber per hectare, but had risen to 1007 kilograms per hectare in 1966. The decrease in yield in Vietnam is due to a combination of circumstances such as the cessation of tapping forced by military action, less experienced labor and less thorough control in the field, herbicide damage, lack of general upkeep of plantations, and the cutting of rubber trees along roads where about 3000 hectares have already been cut. The relative importance of each factor seems impossible to assess. It is a fact that they are all the consequence of the war.

The total yield of rubber in Vietnam has also declined. In 1960, 77,560 tons of dry rubber were produced. Rubber exports amounted to $48,000,000, which was 56 percent of South Vietnam's total exports for that year. In 1967, the yield had dropped to 42,510 tons of dry rubber, which, considering the devaluation of the piaster, amounted only to $12,800,000. Inasmuch as other exports suffered even more heavily, this diminished amount (26 percent of the 1960 exports) made up 72 percent of South Vietnam's exports, which had decreased to $17,800,000, or 20.8 percent of the 1960 exports (*16*).

If a rubber tree is completely defoliated by herbicides, the Institute recommends that planters stop tapping until its new leaves are fully grown. Because it takes a month for a new leaf to grow to full size from the time of breaking of bud dormancy and because dormancy is not usually broken immediately after defoliation, the minimum period of stopping is about 2 months. The maximum period of stoppage is, of course, permanent if the tree is killed. If tapping is not stopped while the tree is defoliated, there is competition between growth of new leaves and yield within the tree, and the future health of the tree is jeopardized. In a number of cases where trees were not killed, tapping has been stopped for as long as 1 year. If only some of the leaves are lost, tapping can be continued, but there is a drop in latex production after a lag of about 1 month. The loss, over a period of a year, has been estimated to be sometimes as much as 30 percent of the normal yield of latex. At current prices that amount of loss reduces profit from about $90 per hectare per year to nothing. As a consequence, most of the small plantations have been unable to stay in business. Only the large planters, with solid financial backing, can afford to remain in operation despite the war.

According to studies by Dow Chemical Company (as reported to us by the Rubber Research Institute), the defoliant is absorbed through the leaves of the trees and is carried down through the phloem within 24-hours, and symptoms of defoliation appear within a few weeks after spraying. The distance the defoliant travels down the tree is a function of the dosage received, and the Institute people have assessed this by the simple device of cutting into the trunk of the trees at different heights to investigate the flow of latex. Necroses are also clearly visible in the sectioned trunks, many of which we examined in the laboratories of the Institute. As might be expected, the smaller the rubber tree, the more readily it is killed by defoliants. Research in Malaysia has shown that a wide range of concentrations of the *n*-butyl ester of 2,4,5-T killed rubber seedlings in 6 weeks (*3*). Accidental defoliations in Vietnam indicate that trees less than 7 years old can be killed by the dosages used in military operations, but that older trees normally recover. Nevertheless, all trees on 100 hectares on Plantation Ben Cui were killed by herbicides in 1965, despite the fact that the trees were 33 years old. From such occurrences, the



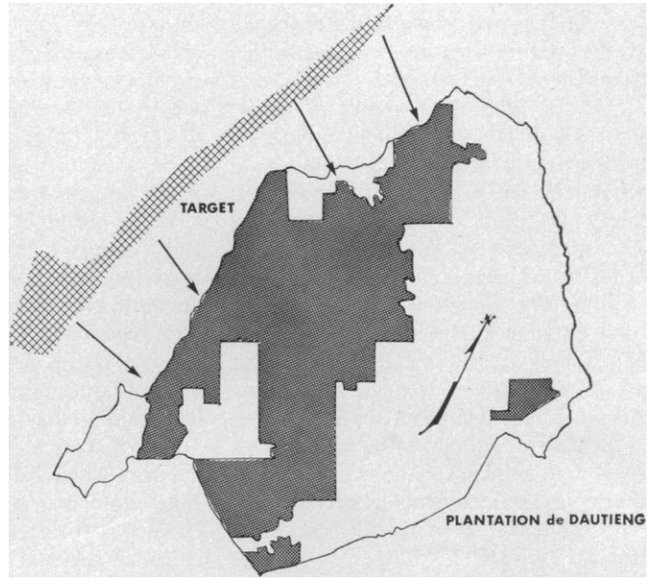


Fig. 3 (left). Target area and areas of rubber trees on Plantation de Dautieng affected by defoliation in February 1965, as indicated by Plantations Michelin. Wind direction is indicated by arrows. Fig. 4 (right). Target area and areas of rubber trees on Plantation de Dautieng affected by defoliation in December 1966, as indicated by Plantations Michelin. Wind direction is indicated by arrows.

Rubber Research Institute concluded that repeated defoliations threaten the very existence of rubber culture in Vietnam (*17*).

In spite of such evidence, Chemical Operations Division, United States Army, claims that rubber trees cannot be killed by defoliants. According to our observations, although we do not claim expertise in this field, damage to rubber production is severe. The Rubber Research Institute, which does not itself maintain any plantations and cannot be accused of bias on that account, seems to be in an excellent position to conduct further research into the physiological effects of defoliants on trees. Funds are urgently needed for this purpose.

Effects of Accidental Defoliation

The extent of damage resulting from wind-blown and gaseous herbicides has been much debated. Agent Orange is classified as a volatile herbicide by plant physiologists, but physical chemists regard it as nonvolatile. Under proper weather conditions nearly all of the spray is deposited on the vegetation or ground within a minute after release from the aircraft. Those vapors formed during fall of droplets subsequently diffuse according to the laws of gaseous diffusion. Therefore, it has been concluded that "The rate of downwind movement of vapors, and therefore the duration of exposure of plants to the vapors, is dependent upon wind speed in the first few minutes subsequent to spray release. *While no quantitative data are available*, it is our considered judgment, based on the above reasoning, that vapors arising during the actual spray operation, as usually carried out, can be dismissed as a source of herbicides for crop damage outside target areas" (*18*) (emphasis added by us). This assumes the existence of inversion conditions and that transport of the liquid spray droplets by the wind is negligible. Our direct observations and interviews suggest that the seriousness of this problem has been greatly underestimated.

We were able to observe defoliation damage to several species of trees far removed from target areas. On 25 March, in the village of Ho-Nai, we observed many fruit trees that had recently been damaged by defoliants. The characteristic sign was the presence of curled, dead leaves on the trees. Damage seemed excessive on the south side of the trees, which suggests that the spray was carried into the village by a southerly or southeasterly wind. Villagers informed us that spray had hit them about 1 week previously. Chemical Operations Division, United States Army, reported to us that a defoliation aircraft had had to jettison its chemicals at the time of takeoff from nearby Bien Hoa Air Base, approximately at the time when the Ho-Nai residents had observed the spray. The most severe damage was to jack fruit (*Artocarpus heterophyllus*, Moraceae) which is also a producer of a milky sap. The residents of Ho-Nai claimed to have been affected by defoliation missions seven times within the past year.

On 23 March, in a residential area between Saigon and the U.S. Air Base at Bien Hoa, we examined and photographed many diseased mango trees. The owner, a biologist trained in the United States, claimed that the trees suffered defoliation 3 years ago, after which they became infected and had not since flowered or produced fruit. In other areas we subsequently observed the same symptoms in mango and other trees. According to the Rubber Research Institute, latex-producing trees seem to be more susceptible to herbicide damage than other species.

Every Vietnamese biologist we talked to explained that actual herbicide damage has been frequent and regular over much of the delta region. In the Ministry of Agriculture we were shown photographs of damaged jack fruit, manioc, and rubber and were told that many guava trees had been killed. The Ministry has attempted in a preliminary way to assess the total damage reported and found it to be so extensive that adequate financial compensation to the owners of damaged trees would probably be impossible. The experimental station of the College of Agriculture of the University of Saigon at Tu Duc has been affected by wind-blown defoliants several times, usually with almost complete kill of vegetables.

It is difficult to determine the amount of claims actually submitted to or paid by the Vietnamese government. Funds for the payment of defoliation claims are provided by the United States, but the claims are handled by the Political Warfare Department of the Air Force of the Republic of Vietnam under the Military Civil Assistance Program. Damage claims are considered and paid by province officials under guidelines established by the central government. Everyone we talked with agreed that payments are minimum. We were told by Vietnamese that people who file claims with the government are often threatened with imprisonment if they continue to press their claims. Many others do not attempt to file claims because they feel it will be of no use. United States officials argue that most claims are fraudulent.

It is our opinion that significant quantities of defoliants are regularly carried by the wind over broad areas of cropland in the Republic of Vietnam. Even given the difficulties of making first-hand observations in a war zone, it would be possible for inde-

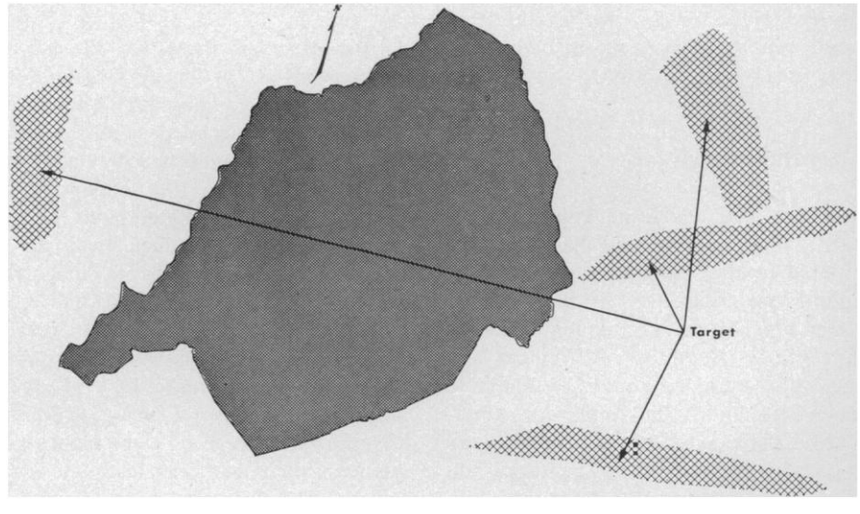


Fig. 5. Target area and areas of rubber trees on Plantation de Dautieng affected by defoliation in May 1967, as indicated by Plantations Michelin.

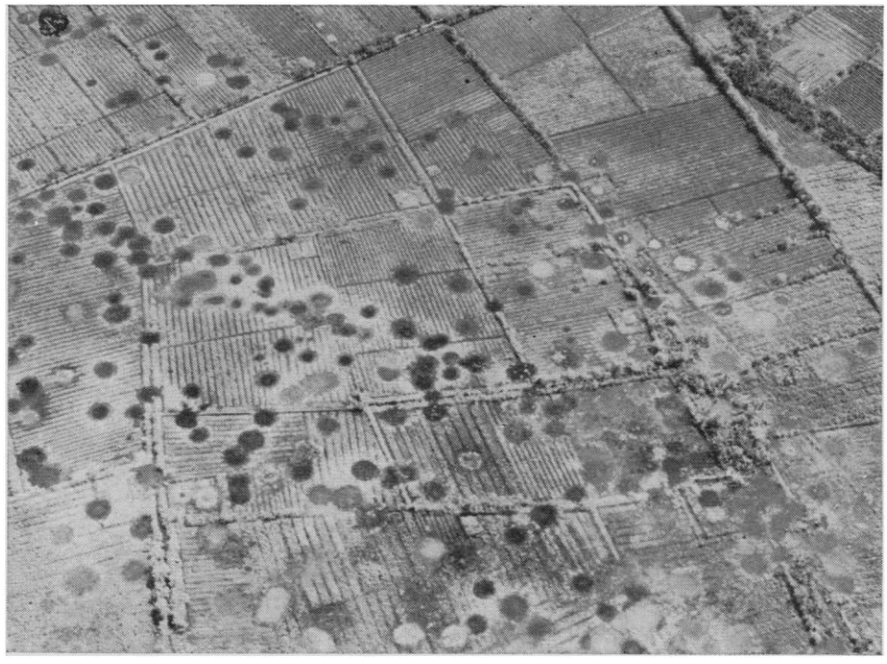


Fig. 6. Craters caused by bombs from B-52 aircraft in manioc fields about 20 miles northwest of Saigon.

pendent observers to verify or disprove many of the conflicting claims. Such a study is urgently needed. Rising damage claims in 1967 caused a serious review of the defoliation program at that time (*19*). Serious controversies over damage caused by wind-blown spray had arisen, and the psychological impact on the Vietnamese was great. It is noteworthy (and substantiates the claims of widespread crop damage) that the United States now has changed its policy and uses primarily agent White in the delta region because its volatility is lower than that of the other available agents. Nevertheless, we encountered many reports of very recent damage in that area.

Crop Destruction

Direct and deliberate application of agent Blue to cropland has been restricted to the highland regions of the country which are held by the National Liberation Front. Consequently, scientists of the Republic of Vietnam and those of the United States are unable to make first-hand studies at present. American officials consider the program very successful because many captured soldiers from these areas are seriously undernourished; some to the extent of being stretcher cases at the time of capture. These reports might suggest that the "resource denial" program has been successful, but there are strong reasons for believing that food shortages affect women, children, and elderly people much more than they affect soldiers (*20*).

Effect of B-52 Bombing

Although it has not attracted the concern of American scientists, the damage caused by raids with B-52 bombers is of considerable ecological significance. The 500- and 750-pound bombs dropped by these aircraft leave craters as much as 30 feet deep and 45 feet across. Most of these are filled with water even late in the dry season. The army does not disclose the total number of bombs dropped, and the total area affected cannot be calculated accurately. However, the magnitude of the effect can be estimated from the following facts. A standard load for a B-52 is 108 500-pound bombs or nearly 30 tons of explosives. Normally, a "mission" consists of 3 to 12 aircraft. In 1967, 982 missions were flown over the Republic of Vietnam. In 1968, 3022 missions were flown (Table 3). If one assumes an average of eight planes per mission, then one can estimate that about 848,000 craters were formed in 1967 and 2,600,000 craters in 1968. As one Vietnamese put it, we are making the country look like the surface of the moon (Fig. 6). Unless heavy earth-moving equipment can be brought to the sites to fill the craters they will remain a permanent feature of the Vietnamese landscape. Areas such as War Zones C and D, which have been heavily hit by B-52 attacks, are riddled by craters.

Since most of the attacks have occurred in militarily contested areas it has not been possible for scientists to investigate heavily cratered areas to determine the effects on local ecology. Obviously, they are potential breeding grounds for mosquitoes; they may possibly be fish-breeding ponds; they may also render many agricultural areas difficult to utilize.

Miscellaneous Effects

The prolonged military activity in Vietnam is causing other ecological upheavals. Not the least are the major sociological changes that are taking place in the country, such as the amazingly rapid rate of urbanization of the population. This results as people flee from war-torn countryside or are forcibly transported to the city. Within the last decade Saigon has changed from a quiet city of 250,000 to an overcrowded city of 3,000,000 inhabitants. The tremendous infusion of American capital has also resulted in rapid increase in the number of motorized vehicles in the streets. Japanese motor bikes and small cars of Japanese or Italian manufacture seem to be prevalent. Traffic accidents are common. Saigon's air pollution problem due to fumes from the mixture of gasoline and oil which serves as fuel is so severe that many trees along the major arterials in the city are dead or dying. (It is possible that the winddrift of defoliants has contributed to weakening the trees, but it is likely that the major cause is fumes from motor vehicles.) There are no immediate prospects for any improvement as the population of the city continues to grow and creation of an adequate municipal transportation system seems improbable.

A major cause of forest destruction in Vietnam today is fire. Some fires are started deliberately by the Vietnamese army and some are caused by artillery shells. Over 40 percent of the pine plantations in the country have been burned recently; the extent of destruction of the mixed forests is unknown. We were unable to estimate the total area involved.

Because of the war, all hunting in the Republic of Vietnam has been officially discontinued. Nevertheless, there are large numbers of armed men in the forest, many of whom are poorly nourished. Presumably, they regularly shoot all suitable food animals. Tigers, on the other hand, seem to have benefited from the war. In the past 24 years, they have learned to associate the sounds of gunfire with the presence of dead and wounded human beings in the vicinity. As a result, tigers rapidly move toward gunfire and apparently consume large numbers of battle casualties. Although there are no accurate statistics on the tiger populations past or present, it is likely that the tiger population has increased much as the wolf population in Poland increased during World War II.

Table 3. Missions flown by B-52 bombers over Vietnam.

Month	I Corps	II Corps	III Corps	IV Corps	DMZ		North Vietnam
					N	S	
			1967				
January	18	14	27	1	2	7	
February	23	30	30	1	1		
March	45	23	32				
April	55	13	22	2	2	4	
May	55	27	23	1	1	3	
June	45	28	25	1			
July	44	31	22	3		3	3
August	26	28	24			24	1
September	13	9	6			57	15
October	17	15	20			30	27
November	13	47	16	1		12	9
December	6	19	22			27	8
			1968				
January	59	22	23			4	1
February	204	53	34				
March	222	58	27	4		6	
April	173	66	19	7		2	
May	71	123	27	10		13	1
June	24	87	171	11	4	6	
July	28	34	152	26	7		45
August	71	55	161	13	8	8	8
September	51	55	167	18	1	10	8
October	86	33	128	25	2	1	15
November	45	36	109	17			
December	53	22	125	17			

Summary and Conclusions

In Vietnam the chemical weapons of a technologically advanced society are being used massively for the first time in a guerrilla war. In this conflict there are no battle lines, no secure territory, and no fixed, permanent military installations which can serve as targets for attack. Rather, the military efforts are aimed at increasing the toll of fatalities, denying food to the enemy, and depriving him of the cover and concealment afforded by natural growth. This type of warfare is, therefore, extremely destructive, both of human lives and environment. Our own observations showed the profound effects of denuding the country of growth. The military is emphatic about the effectiveness of defoliation in reducing American casualties significantly. The demand for the services of 12th Air Commando Squadron greatly exceeds their ability to supply them. Although the total number of requests for defoliation missions was not disclosed, we were told that even if no further requests were made, the defoliation crews would be kept busy for years by the present backlog. The current extent of the defoliation program is not determined by military demand nor by any considerations of saving the ecology and viability of the land and natural resources of Vietnam, but solely by competition for equipment and personnel.

With general agreement among military experts that defoliation is a potent weapon in guerrilla warfare, it is to be expected that in any future wars of this nature more extensive use will be made of it. At the end of their war against the Vietnamese, the French discovered the usefulness of helicopters as field combat aircraft, but they had only about a dozen at their disposal. There are now several thousand helicopters in Vietnam as a major component of our offensive air power. Making a realistic appraisal of defoliation and its ecological consequences, we must, therefore, consider not only the present extent of use but also anticipate greatly expanded defoliation actions in the future.

We consider that the ecological consequences of defoliation are severe. Enough is now known to reveal that a significant fraction of mature trees in most forests are killed by single applications of herbicides and that almost complete kill, including destruction of seedlings and saplings, is to be expected if repeated sprayings are made. Because of military demands for respraying, we must expect virtual elimination of woody vegetation of defoliated sites as a common result of the military use of herbicides.

It is evident that the most stringent regulations for the application of defoliants cannot prevent the widespread dispersal of herbicides to areas far beyond those that were intended to be defoliated. We found abundant evidence of repeated moderate to severe defoliation of trees and herbs in areas many miles removed from sites of direct application. Every responsible Vietnamese person we met confirmed this. Moreover, a pilot in a war zone will jettison his load of defoliant, rather than jeopardize the safety of his crew and plane, and a spray plane will not return to its base with a full tank because its crew found the temperature or the wind velocity higher in the target area than anticipated. Military use of defoliants will inevitably result in herbicide damage to areas that are far more extensive than those specified as targets.

It is evident that the defoliation program has had tremendous psychological impact upon the Vietnamese people and has profoundly affected their attitude toward Americans. A farmer whose entire crop has been destroyed by herbicides, whose fruit trees do not bear fruit for 3 years, will inevitably be resentful. We were told repeatedly, though politely, that a significant deterioration of attitudes toward Americans has resulted from the massive use of defoliants. The claim that defoliation is more humane than other weapons of war because it does not directly cause human casualties, may appeal to those whose land has

not been defoliated, but hardly to those whose food supply or property has been destroyed. A realistic assessment of the effects of defoliation must take into account the psychological effects upon the people.

The politically sensitive nature of effects of defoliation is fully recognized by the military authorities. Although they claim that defoliants produce no long-term effects on the environment, they have instituted the most stringent regulations to govern their use. The Army claims that it is more difficult to get permission for the defoliation of trees in Vietnam than for killing persons, and permission to spray rubber trees has never been granted, according to military sources, even when enemy forces were "known" to use plantations for concealment. It seems that preferential treatment of the politically powerful rubber interests in Vietnam has added to the hostility of the poorer Vietnamese.

The secrecy surrounding the use of defoliants in Vietnam has also contributed to the feelings we have reported above. The government of the Republic of Vietnam and American officials have not disclosed information to the Vietnamese about the agents used, areas sprayed, and the nature of the chemical action of defoliants and herbicides. The most concerned Vietnamese scientists did not know the chemical composition of the herbicides even though they have tried to ascertain it from their government.

Recommendations

American scientists will want to know what investigations might be immediately possible to sift facts from among so many conflicting claims regarding the ecological effects of defoliants and to stem the tide of increasing mistrust between the Vietnamese and the Americans. Support for research projects should be initiated by the American scientific community without delay. In Vietnam there are scientists, well-trained at American and European universities, who are deeply concerned about the effects of the war on their country. They are eager to conduct research that is necessary for the rehabilitation of their ravaged land. The flora and fauna of the country are well known. The Rubber Research Institute of Vietnam continues to function, although it has once been displaced by military action. It is capable of expanded research into the physiological effects of defoliants on rubber trees and other species. Its staff is interested in investigating the possibilities of diversifying so that it can advise rubber planters on avoiding complete dependence upon rubber. A modest investment of funds for Vietnamese scientists is likely to produce important research results. It would also improve Vietnamese relations with American scientists.

Although long-term studies, such as following vegetational succession on heavily defoliated areas, would be impossible for Vietnamese (Saigon) or American investigators, there are no insuperable barriers to the investigation of fish diseases, of methods of minimizing herbicide damage to commercially important trees which have been deliberately or inadvertently sprayed, and of further studies of toxicity to animals. It should also be possible to gather soil samples from areas that have been subjected to different treatments to learn more about the fate of arsenical compounds, their effects on soil microorganisms, and possible accumulation in the soil of the more persistent herbicides such as picloram. We urge that such studies be initiated now rather than be delayed until hostilities cease, although obviously the difficulties are great. We recommend most strongly that the American Association for the Advancement of Science, in accordance with its resolutions of 1966 and 1968 (*21*), take the initiative in setting up an international research program on the long-range effects of the military use of herbicides in Vietnam. We believe that such action is necessary if United States scientists wish to maintain (or regain) the respect of scientists in Southeast Asia.

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