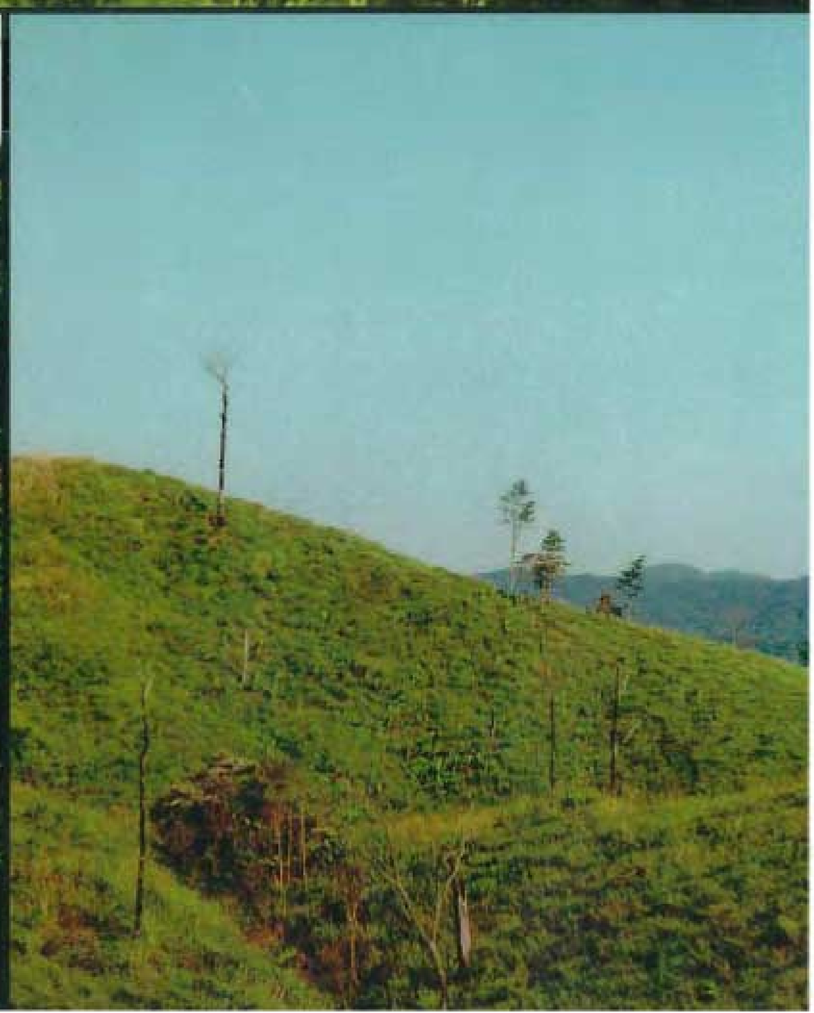
PRELIMINARY ASSESSMENT OF ENVIRONMENTAL IMPACTS RELATED TO SPRAYING OF AGENT ORANGE HERBICIDE DURING THE VIET NAM WAR

Hatfield Consultants Ltd., West Vancouver, Canada
10-80 Committee, Ha Noi, Viet Nam

Volume 1: Report



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VOLUME 1: REPORT

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Front Cover Photos

- Top: C-123 applying herbicide over upland forest in Viet Nam. Photo courtesy of Dr. E.W. Pfeiffer, Missoula, Montana.
- Lower Left: Forested area near Aluoi Valley, untouched by herbicide (Hatfield Consultants Ltd. photo, January 1995).
- Lower Right: Once-forested area near Aluoi Valley that received herbicide during the Viet Nam War (Hatfield Consultants Ltd. photo, January 1995).

Back Cover

- Radarsat image of Aluoi Valley with herbicide spray lines superimposed (*cf.* Plate 5.1).

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PREFACE

We first visited Viet Nam in October of 1993. By that time, international financing institutions such as the World Bank and Asian Development Bank, donor agencies and private sector investors were making significant commitments in the country. A host of environmental and natural resource management problems needed to be addressed. One of the lingering environmental problems from the Viet Nam war years identified by the Vietnamese was the issue of determining the past and present environmental and health effects of Agent Orange dioxin.

Our company has been monitoring and studying the extent of dioxin contamination in marine and river-bottom sediments and food-chain organisms in the vicinity of pulp and paper mills in British Columbia for the past ten years. We have been working with these companies and government regulatory agencies, to assess environmental effects of removal of the dioxin contaminant from pulpmill effluent. The Viet Nam Agent Orange dioxin situation was therefore of particular interest to our dioxin study team.

Through the Canadian embassy in Ha Noi, we made contact with the Vietnamese government 10-80 Committee (established in October 1980), a team of medical doctors mandated to study "*the consequences of the chemicals used during the Viet Nam war*". We formed a working agreement with this agency to carry out more systematic studies regarding the Agent Orange issue than had been carried out to date, particularly related to environmental food chain components.

Funding has been a problem from the start of our work. However, with funding from Vietnamese training and technology testing programs, we managed to carry out the dioxin contamination pilot program reported here. Over the past four years, our project team has spent approximately 850 person days in the country and about the same time in Canada writing proposals and reports, planning field trips and analyzing data. We have received excellent participation/cooperation during our work from the 10-80 Committee and the Vietnamese natural resource management agencies. Our counterparts in the Vietnamese 10-80 Committee, forestry agency, Ha Noi University and provincial health agencies have been critical to in-country information procurement and data compilation/analyses. This report was initially written by our project team and subsequently reviewed by our counterparts in the 10-80 Committee who provided comments, additional information, etc. The 10-80 Committee is accordingly co-author of this report. We have received full cooperation from all Vietnamese government agencies during our programs.

As the study progressed, our project team met, or spoke by telephone, with a number of Vietnamese and American technical and military personnel directly involved with the Agent Orange issue. In addition, Canadian study team members have assembled a small library related to the Viet Nam war and associated conflicts in Laos and Cambodia. Books written during the war years and up to 1998 were consulted. Quotes from these sources relevant to the Agent Orange issue have been cited in this report to provide the reader with some insight into the viewpoint of various factions both during the war and to the present day.

This information provided the study team with an understanding of such issues as how, when and where spraying took place, and why the program was terminated. Various pieces of anecdotal information such as how empty herbicide barrels were handled at U.S. bases, descriptions of a herbicide tank leak at Bien Hoa airbase, spray plane herbicide load jettisons, crashes, etc., provided background explanations for impact observations and data interpretation.

From our work in Canada, we were aware of the persistence of dioxin and its ability to bioaccumulate and biomagnify in the food chain. However, we were challenged with designing a sampling program which would fulfill our study objectives without spreading our data points over such a large area of Viet Nam that results would be difficult to interpret. Therefore, after preliminary reconnaissance trips, we chose to concentrate on one relatively remote area for the pilot study, the Aluoi Valley. We compiled natural resource and socio-economic data from this region for two years prior to designing our dioxin sampling program. Satellite imagery was used as a tool in compiling resource information and determining our sampling locations later in the project.

Our report has included a large amount of scientific information and data to make it as comprehensive as possible to people with specialist knowledge related to the subject. We have also attempted to write the report and present graphical summaries so that non-specialists can more easily follow its main points and conclusions.

The number of dioxin samples analyzed has been limited by funding constraints. However, we believe the weight of evidence from our pilot program indicates there are some serious problems in Viet Nam related to environmental contamination and human health risks due to Agent Orange dioxin. If such data were collected in most western jurisdictions, based on similar sampling levels, major environmental clean-up and more extensive studies would be mandated and implemented. As western-based scientists, we can hardly recommend less be done in Viet Nam.

We believe much more environmental and human health work needs to be carried out in the country related to the Agent Orange issue. Results of such work would be of benefit not only to the Vietnamese, but to a wide international audience interested in exotic chemical environmental and human health issues. All Viet Nam war veterans from all combatant countries would also have a strong interest.

Our technical team has found this Viet Nam project to be so technically challenging and of such high humanitarian interest that we have expended considerable uncompensated company resources and personel time on tasks related to the work. Viet Nam is an intriguing country. We have experienced many adventures in some of the most remote areas in the world, where millions of people are living on the edge between sustenance survival and starvation. We believe these people deserve our assistance in solving their Agent Orange problem.

Chris Hatfield
President
HATFIELD CONSULTANTS LTD.

EXECUTIVE SUMMARY

OVERVIEW

Hatfield Consultants Ltd. (West Vancouver, Canada) and the government of Viet Nam 10-80 Committee (Ha Noi, Viet Nam) cooperated in studies involving the determination of dioxin levels in the environment of Viet Nam. The investigation covered the period 1994-1998.

Dioxin was a contaminant present in Agent Orange, a herbicide applied in southern Viet Nam during the second Indochina war (commonly referred to as the Viet Nam war). The history of herbicide spraying and the chemicals used in southern Viet Nam is well documented.

The issue of dioxin impacts on the health of Vietnamese people and the Vietnamese environment is politically charged. Although it is widely accepted that dioxins accumulate and persist in humans, the linkage between dioxin levels in the environment and specific human health effects is controversial. There are virtually no data on acute toxicity in humans; the field focuses primarily on long-term chronic toxicity and congenital birth defects.

The sophisticated analysis and subsequent high cost required for dioxin sample analyses and the post-war isolation of Viet Nam has hampered in-country dioxin sampling and analyses. Although Viet Nam has qualified scientists, procurement of adequate funding for dioxin-related research has been a problem, given other pressing health and economic concerns.

The literature on impacts of dioxin on the Vietnamese natural environment and its components is particularly deficient. There have been no systematic, comprehensive, well-designed environmental studies of residual dioxin contamination from war-time herbicide applications. This preliminary technical assessment was undertaken to begin filling this gap. The study presented here describes two field sampling expeditions (January 1996 and November 1997) which were undertaken to collect and analyze environmental samples.

The Aluoi Valley in central Viet Nam, near the Laos border, was selected as our study area in order to minimize the anthropogenic influences of the more urbanized or intensive agricultural areas farther south. A greater degree of industrialization may be accompanied by environmental input of dioxin and other contaminants (e.g., waste-water discharges, air emissions) which have the potential to confound data interpretation.

The Aluoi Valley was heavily sprayed (from approximately 1965 to 1970) principally with Agent Orange and to a lesser degree Agent Blue and Agent White. Inhabitants of Aluoi are primarily hill tribes living "off the land" at a more or less subsistence level. Manioc, rice, sweet potato, pond-cultured fish, duck, chicken, and some beef and pork are consumed (the mammals being consumed less frequently).

Several visits to Viet Nam, including consultations with various Vietnamese government departments, Peoples' Committees, etc., preceded our sampling program. The areas to be sampled and media to be collected for subsequent analyses were carefully selected prior to field collection activities in Aluoi Valley.

The 1996 sampling expedition consisted of a wide-spectrum sampling approach throughout the valley. Data from the 1996 program revealed that the commune of A So, situated in the southern sector of Aluoi, contained soils and fish tissues with dioxin concentrations (soils, 33.3 pg/g and 112.6 pg/g TEQ; fish tissues, 2.6 pg/g and 53.7 pg/g TEQ).

Data from 1996 formed the basis for a more focussed expedition in 1997 in A So and a small former U.S. Special Forces airbase in the area. The study was designed to follow the pattern of dioxin movement through the food chain in this relatively restricted area.

Farmer's soil, former airbase soil, fishpond sediment, cultured fish and duck tissues and human blood were collected from A So in 1997. A parallel sampling program, undertaken as a component of a concurrent satellite remote sensing study (RADARSAT) by Hatfield, enabled the collection of soils and aquatic sediments from the heavily sprayed Ma Da forest area of southern Viet Nam (northeast of Ho Chi Minh City [HCMC]).

As in the 1996 expedition, former U.S. airbase soils contained the highest levels of dioxin (92.2 pg/g and 901.2 pg/g TEQ); the 2,3,7,8-T4CDD congener made up 96% and 99.6% of the total TEQ for these samples, respectively. These data indicate that the origin of 2,3,7,8-T4CDD is related to Agent Orange, given this congener was the principle contaminant in Agent Orange accompanying the 2,4,5-T herbicide portion of the Agent Orange mixture.

Human blood samples ranged from 14.3 pg/g to 37.2 pg/g (TEQ, lipid basis). These levels were recorded in pooled blood from females >25 years of age and males >25 years of age, respectively. Males and females 12-25 years of age exhibited pooled blood dioxin levels of 25.5 pg/g and 15.4 pg/g (TEQ, lipid basis), respectively. Each age/sex category of blood sample consisted of a pooled sample size of N=50 individuals. The 2,3,7,8-T4CDD (Agent Orange) congener in blood samples was a significant contributor to the total TEQ value (77% - 83%).

Data indicate that former airbase soils and soils in the vicinity of other former military installations in Viet Nam may be contaminated with 2,3,7,8-T4CDD if these facilities experienced any activities related to the Agent Orange spraying program. The ultimate receptacle for 2,3,7,8-T4CDD moving through the local environment near A So is human beings. In this isolated valley both the older and younger generation have significant levels of dioxin in their blood relative to data from northern Viet Nam where Agent Orange was not applied. Deformities and early cancers have been noted in the valley; however, a thorough epidemiological investigation is required before defensible conclusions regarding the relationship between 2,3,7,8-T4CDD exposure and human health problems can be drawn.

The detection of dioxin in the younger generation provides evidence that the environment remains contaminated and dioxin is presently moving through the food chain into humans. One probable path of this contamination is via the excavation of cultured fishponds in contaminated soils. These re-mobilized dioxins are taken up into fish/duck tissues and ultimately transferred to humans. Other routes of transfer probably exist, one of which may be direct exposure from contact with contaminated soils.

Our data indicate that pesticide residues (principally DDT and its metabolites) in the Aluoi Valley are lower than concentrations in soils from reference sites.

CONCLUSIONS

1. Soils contaminated with dioxin, originating from the herbicide Agent Orange, were found at a small former U.S. airbase and airstrip situated in A So commune in the Aluoi Valley, Viet Nam. Levels found would probably result in such an area being declared a "contaminated site" if it was located in most western jurisdictions. Agent Orange dioxin was also detected at lower levels in soils collected from farmer's fields.

2. Dioxin contamination related to Agent Orange was found in grass carp growing in fishponds excavated out of the terrain in the vicinity of the former Aluoi Valley airbase. Levels found would trigger a consumption advisory process (i.e., recommendations on maximum human consumption levels) and possibly prohibitions against consumption if they were from a location in Canada or other western jurisdictions.

3. A consistent pattern of food-chain contamination by Agent Orange dioxin was found in the airbase area which included soils, fishpond sediment, cultured fish, ducks and humans.

4. Other areas sampled in the Aluoi Valley exhibited Agent Orange dioxin levels below those considered threshold values in western jurisdictions. However, a more comprehensive dioxin sampling program may find other contaminated "hot spots" in the area. Agent Orange dioxin contamination, accumulation and magnification of levels found in soils and fishpond sediment could occur in other areas of Viet Nam, as illustrated by the A So data. Given data from the Ma Da region, the existence of other "hotspots" in Viet Nam is likely.

5. Relatively high levels of dioxin (particularly the 2,3,7,8-T4CDD congener, characteristic of Agent Orange) were found in human blood of populations living near the former A So airbase in the Aluoi Valley. People living in this isolated region who were born after the war also possessed high dioxin levels relative to unsprayed areas of northern Viet Nam, indicating a continuing process of dioxin uptake caused by contamination of the food chain.

6. Human health data collected in A So and adjacent Huong Lam communes by Vietnamese medical personnel, indicate that visible physical birth defect rates are an order of magnitude higher in these communes than in similar communes in northern unsprayed Viet Nam. The data are suggestive of a direct relationship between levels of Agent Orange dioxin contamination in the environment and effects on human health. Further studies by a

multinational medical team of specialists familiar with assessing dioxin health issues should be carried out to confirm this relationship.

7. Since Agent Orange spraying was particularly heavy in the vicinity of former U.S. military installations (airbases, fire support bases, naval bases, etc.), the environmental contamination findings indicate that such areas may still contain contaminated soils and food chain components leading to significant human exposure and uptake. This is particularly likely near major former U.S. airbases where large quantities of herbicides were transported, stored and/or handled (e.g., Bien Hoa, Tan Son Nhut, Da Nang).

8. Agent Orange and other herbicide spraying activities during the war resulted in dramatic land use changes in southern Viet Nam. Large areas of formerly forested land have been replanted with agriculture plantations or developed for shrimp farming.

9. Large areas of former upland and mangrove forested land once affected by herbicide spraying, continue to be affected by human activities involving the utilization of dead vegetation for lumber and firewood. Forested land continues to be affected by human activities.

10. Areas of coastal mangrove forest in the Rung Sat (Saigon River delta) and Ca Mau (Mekong River delta) have been rehabilitated by Vietnamese agencies. Many bird and animal species are returning to these areas. Some areas of the herbicide-affected former upland forest have been rehabilitated, but most of these areas remain as barren wasteland which has been invaded by coarse grass species that prevent natural forest regeneration. Vietnamese government and community agencies have ambitious forest rehabilitation programs at the planning stages. The success of the programs is limited by financial resources.

RECOMMENDATIONS

1. A public health protection plan is required for the A So area to ensure local people do not ingest foods contaminated with Agent Orange dioxin, nor are exposed through other routes. The consumption of high lipid content foods (e.g., fish fat) from contaminated areas should be avoided. Plant foods grown beneath the surface of the soil should be washed thoroughly with the outer skin removed prior to cooking/consumption to remove potentially contaminated soil.

2. Decontamination of soils by high temperature incineration is too expensive to be a realistic mitigation technique in Viet Nam at this time. Other mitigation plans are required to decontaminate or isolate areas presently contaminated with Agent Orange dioxin, such as the former A So airbase, to reduce human exposure. Temporary mitigation methods such as increasing the importation of marine fish species and, if necessary, other food from non-contaminated areas should be considered.

3. Additional blood sampling and testing should be performed throughout the Aluoi Valley to determine whether the high dioxin levels recorded in humans from A So occur in other areas of the valley, or whether this is an isolated data set related specifically to inhabitants living in close proximity to the former airbase.

4. Further assessments of dioxin contamination are required near all former U.S. military bases/facilities in Viet Nam, where use/storage of Agent Orange during the war likely occurred, to determine the level of Agent Orange related dioxin contamination and reduce human exposure. Studies of other geographical areas in Viet Nam over which heavy Agent Orange spraying occurred (aerial and land based applications) are also required. Such studies should consist of comprehensive food chain assessments, including humans.

5. Where additional sites are identified as being contaminated with dioxin, environmental impact mitigation and public health protection plans should be developed and implemented.

6. Studies of human health should be carried out in communes / villages near areas where soils or the human food chain are found to be contaminated with Agent Orange dioxin. Comprehensive epidemiological studies are required in Viet Nam if the relationship between environmental contamination with Agent Orange dioxin and human health effects is to be better determined.

7. If higher than normal birth defects, cancers or other health effects are found to occur in contaminated areas, special health clinics or treatment centers should be established to treat people affected by Agent Orange dioxin contamination. In the Aluoi Valley, the existing health clinic at A Ngo should be consolidated and improved to support adjacent villages, rehabilitate any handicapped people and provide advice to local people on health issues related to dioxin contamination.

8. Where clearing programs for unexploded ordnance are underway, parallel studies on soil contamination should be carried out to ensure re-disturbance of contaminated soils in these areas does not result in the creation of unacceptably high dioxin levels through re-mobilization in the environment. Such disturbance could make dioxin more accessible to elements in the local food chain and humans.

9. Sediment cores should be collected and analyzed from coastal areas which drain heavily sprayed regions or major former U.S. military bases in southern Viet Nam. Sediment core analyses in British Columbia (Canada) have shown stratified deposition of dioxins over time. Activities such as dredging or trenching in deposition areas could resuspend dioxin into the water column and potentially into the food chain.

10. Although the general areas of impact of Agent Orange on upland forests are known, thorough inventories, delineation, and updating of deforested areas are desirable. Satellite technology involving remote sensing imagery would be the most cost-effective way of carrying this out.

11. Vietnamese forest rehabilitation scientists have developed sound techniques for rehabilitating upland forests in areas sprayed with Agent Orange in southern and central Viet Nam. Some upland forest rehabilitation is now taking place in the country. These activities should be expanded significantly with funding from international agencies. Community forestry projects and flora/fauna biodiversity programs should be integral to these upland forest rehabilitation efforts. Programs have been successful in other regions of Viet Nam where local people have been given ownership and management control of land and forest areas in return for commitments not to destructively cut or burn forest areas for farmland. Such undertakings could include planting trees for lumber and industrial use and managing grasslands for livestock. The government of Viet Nam is prepared to provide the necessary financial and temporary food source support for families willing to participate in such forest rehabilitation programs.

12. Viet Nam, with its heavily sprayed areas in the south and reference areas in the north where no spraying took place, represents an excellent site for study of human health and environmental effects caused by exotic chemicals such as Agent Orange dioxin by scientists from the international community. Present world standards for soil and human food contaminated with dioxin represent only best estimates for human health safety. However, billions of dollars of industrial investment decisions, clean-up requirements and human health protection decisions are being based on these estimates. These standards would be more effective and credible if they were based on more comprehensive, hard scientific data. Viet Nam may be considered one of the best locations in the world to find solutions to the many questions and concerns regarding dioxins in the environment and their effects on human health.

13. Based on the levels of environmental contamination by Agent Orange dioxin found during this investigation, there is an urgency to carry out further programs of the nature outlined above to reduce the risk to human health posed by contaminated sites in Viet Nam.

ACKNOWLEDGEMENTS

PROJECT FINANCIAL AND IN-KIND SUPPORT

Project components were provided with funding assistance from various Canadian government programs over the 1994-1998 period. Each government program had other objectives in addition to those related to herbicide impact assessment reported in this study. All Canadian government agency programs involved training and/or technology transfer as their main purpose. The dioxin study was carried out as part of these programs; this study involved a real world situation as a training component. Training and technology transfer needs, therefore, took precedence over dioxin study needs during the program. The budget for such items as dioxin sample analyses was, as a result, limited. Canadian government agencies involved, titles of programs, their objectives and report titles of non-herbicide impact studies are summarized in Table 1.1.

The project team gratefully acknowledges the financial contributions of Canadian government agencies and the in-kind support from Vietnamese agencies involved in the study. Without these contributions, the work could not have been carried out.

In Viet Nam, the following people provided particular assistance:

- Prof. Dr. Vo Quy – Centre for Natural Resources and Environmental Studies University of Ha Noi. Dr. Quy conducted ecological studies on the effects of Agent Orange spraying during and after the war. Dr. Vo Quy provided very helpful advice related to areas for further study in Viet Nam;

- Dr. Nguyen Thi Ngoc Phuong – Director of Tu Du Obstetrical and Gynecological Hospital HCMC. Dr. Phuong provided birth defect information and statistics;

- Ho Thi Phuong Dai – Project Coordinator for Japan International Volunteer Centre (JIVC), an NGO conducting a small enterprise agriculture development program in the Aluoi Valley. The JIVC provided information on socio-economic parameters of people in the Aluoi Valley; and

- Truong Dang Khoa – Project Officer of Nordic Assistance to Viet Nam, an NGO working on small-scale-enterprise aquaculture development programs in the Aluoi Valley. This NGO provided information on socio-economic parameters of people in the Aluoi Valley.

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In North America, the following people provided assistance:

- Donald C. Hakenson – Director U.S. Army and Joint Services Environmental Support Group (ESG) Washington, DC. Mr. Hakenson provided references for spray mission coordinates and other information related to the herbicide spraying program;

- Dr. E. W. Pfeiffer – Professor of Zoology and Environmental Studies University of Montana (1959-1990), now Professor Emeritus, University of Montana. Between 1969 and 1983, Dr. Pfeiffer was a member of teams that visited Viet Nam on several occasions to investigate the consequences of Agent Orange use during the conflict. Dr. Pfeiffer provided historical and political information and technical papers related to the issue;

- Richard S. Christian – Retired Deputy Director for Research and Technology Assessment, American Legion, Washington, DC. Mr. Christian provided insight into U.S. troop locations and movement during the war;

- Richard Turle and Chung H. Chiu – Environmental Technology Centre, Environment Canada, Ottawa. The ETC provided analytical services for some Viet Nam dioxin samples, calibrated reference material, and a capability review on Viet Nam dioxin laboratories; and

- Dr. C. Hamilton, Vice President, Analytical Services and Brian Fowler, Senior Analytical Chemist, Axys Analytical Laboratories, Sydney, BC, Canada. Axys conducted most of our Viet Nam dioxin sample analyses and provided training of Vietnamese personnel at their lab in Canada and in Viet Nam dioxin labs in Ha Noi and Ho Chi Minh City.

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- Marius R. Grinius – Ambassador; Canadian Embassy, Ha Noi;

- Pete Peterson – Ambassador; Embassy of the United States of America, Ha Noi;

- David C. Dix – Counselor; Canadian Embassy, Ha Noi;

- Michael D. Eiland – First Secretary Science, Technology, Environment; Embassy of the United States of America, Ha Noi;

- Dr. Arnold Schecter – Professor of Preventive Medicine, SUNY Health Science Centre, Clinical Campus at Binghamton, State University of New York;

- Peter Hoffman – Counselor, Canadian International Development Agency; Canadian Embassy, Ha Noi;

- The Honorable Raymond Chan – Secretary of State (Asia Pacific), Government of Canada;

- Dr. Han Kang – Director Environmental Epidemiology Service, U.S. Dept. of Veterans Affairs, Washington, DC; and

- E. R. Zumwalt, Jr., Admiral, U.S. Navy (Retired) – Former commander of in-country U.S. naval forces during the Viet Nam war, and former chairman of Joint Chiefs of Staff, Washington, DC.

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1 INTRODUCTION

"Environmental damage was an important tactic as well as a repercussion of the Second Indochina War of 1961 to 1975. The strategy involved the destruction of the natural resource base essential to the agrarian society. The theatre of these operations was mainly southern Viet Nam. The result was not only heavy direct casualties and continuing medical complications, but also the widespread disruption and degradation of productive ecosystems" (World Bank 1995a).

HISTORICAL PERSPECTIVE - AGENT ORANGE IN VIET NAM

Although the Viet Nam conflict started in earnest more than 30 years ago, today there remains much controversy over a weapon targeted exclusively at vegetation and not enemy soldiers. The weapon was a group of herbicidal chemicals used for some years in civilian agriculture. Although these chemicals were used in civilian applications, one of the concerns regarding their use in Viet Nam was application rates. Westing (1984a) states "...the routine military herbicide applications [in Viet Nam] were at least an order of magnitude heavier than comparable civil ones".

The most controversial of these herbicidal chemicals was known as "orange herbicide" or, as it became known, Agent Orange. The designation "Orange" originated from the orange stripe that was displayed on barrels containing the orange herbicide mixture. It was a 50/50 mixture of 2,4-D (2,4-Dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-Trichlorophenoxyacetic acid).

The spraying program by the U.S. Air Force began in 1961 in a modest manner, but developed into an extensive operation which lasted until 1971. Large C-123 cargo planes were used, each with a capacity of one thousand U.S. gallons of Agent Orange. Normally the payload was dispensed in a single continuous spray pattern approximately 14 km in length for a run duration of approximately 4½ minutes (Cecil 1986).

As spraying progressed, the U.S. and world scientific community became increasingly concerned regarding the spraying program in Viet Nam. The first group of American scientists to express their concern was the Federation of American Scientists in 1964. They objected to what appeared to be the use of a foreign country, Viet Nam, as a battlefield proving ground for biological and chemical warfare. They pointed out that this was in violation of the Geneva Agreements of 1925 on the use of chemicals in warfare. In 1966 the American Association for Advancement of Science (AAAS), the largest scientific group in the United States, issued a resolution which called for a field investigation into the herbicide spray program, given nothing was known to the scientific community regarding the effect of military use of herbicides on the biological systems of Viet Nam.

Such was the feeling in the U.S. scientific community that in 1967 seventeen Nobel Laureates were joined by over 5000 other scientists in signing a petition to immediately stop the use of these herbicidal chemicals in Viet Nam. The petition was delivered to the U.S. government; however, no action was taken. The AAAS resolution, however, did not suffer such a fate, although it did run into many difficulties. The resolution became politicized although it was strictly a scientific proposal.

In 1969, it was found that one of the components of Agent Orange (2,4,5-T) was teratogenic (fetus-deforming) in laboratory animals (Nelson 1969). Courtney *et al.* (1970) also showed that 2,4,5-T adversely affected fetal development and viability of laboratory animals. Analyses of the 2,4,5-T Courtney *et al.* (1970) used in their experiments showed the presence of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (2,3,7,8-T4CDD, or simply TCDD).

In 1970, the AAAS mounted an expedition to visit Viet Nam and study the ecological effects of the defoliation program. Although the Department of Defense position in 1966 was that competent scientists from around the world stated no adverse effects to living systems would result from the defoliation program, the AAAS study showed that *"the chemicals had seriously damaged the ecology of Viet Nam and may be a serious threat to health, livelihood and social structure of Viet Nam hill tribes"*. The impact of the AAAS study on the government was such that the rapid phase-out of the herbicide program in Viet Nam was ordered, and the U.S. National Academy of Sciences (NAS) undertook a field study along the lines of that carried out by the private AAAS.

The conclusions of the NAS study were very clear. They indicated much damage had occurred to Vietnamese ecosystems, and warned that dioxin effects may seriously affect the health of the Vietnamese people. The 1974 NAS report called for immediate studies focussing on the effects of dioxin on the people of Viet Nam – *"In view of the very high toxicity of TCDD to animals and the presence of this substance in Agent Orange, which was widely distributed in Viet Nam, long term studies to obtain a firmer basis for assessing the potential harmful affects of TCDD on man are recommended. Repeated systematic sampling and analyses of materials from Viet Nam should be started immediately."*

Since the end of the Viet Nam conflict, there has been much litigation by United States soldiers who served in Viet Nam claiming health damage due to Agent Orange. Again, the National Academy of Sciences produced several studies on U.S. veterans. However, no agency has carried out the National Academy of Sciences recommendation of 1974.

PRESENT DAY ENVIRONMENTAL SITUATION IN VIET NAM

Numerous areas within Indochina require environmental impact assessment and subsequent rehabilitation of damage caused by the second Indochina war. The most visible residual environmental damage includes tree and forest removal as a direct consequence of herbicide applications. Other war activities such as bombing and shelling, forest burning, bulldozer vegetation clearing, and wetland draining also severely affected the environment.

Prior to the war, many of the affected areas contained ecologically diverse ecosystems. These ecosystems were substantially altered or destroyed as a result of military operations. Since the end of the war, Vietnamese scientists have collected a substantial amount of information on specific environmental components throughout Viet Nam. Apart from overview ecological studies reported in Westing (1984 a,b) a decade after the war, no systematic, comprehensive long-term environmental studies have been carried out and reported in the technical literature by western scientists familiar with the Environmental Impact Assessment process; in-depth studies in Viet Nam on dioxins were not part of these earlier investigations. Current dioxin contamination levels in the environment resulting from herbicide applications are not well known. This situation has limited the ability of Viet Nam to attract international donor and bank funding to rehabilitate agriculture areas, forests, and basic environmental resource related infrastructure (e.g., flood control facilities, drainage systems, water supply systems, etc.). Many areas in Viet Nam remain to be cleared of chemical contamination, mines and other unexploded ordnance.

Hundreds of thousands of hectares of badly eroded and deforested land remain to be better assessed and reforested. The present health of many rare and endangered wildlife species in war-damaged areas require better documentation. Potential fisheries rehabilitation in Viet Nam watercourses requires analysis; an action plan containing recommendations on how potential war-related food chain contaminant problems could be avoided or overcome requires formulation. Mitigation plans and integrated environmental management plans related to how war-impacted areas could be rehabilitated need to be generated.

Recent medical data have demonstrated that populations in southern Viet Nam have elevated levels of dioxins in their blood and other body tissues relative to unexposed populations in northern Viet Nam. The relationships between wartime herbicide applications, environmental levels of dioxins, ecosystem impacts, and human health issues are of wide international interest, however, comprehensive programs addressing these issues have yet to be initiated.

RATIONALE FOR THIS STUDY

This preliminary environmental impact assessment of residual damage caused by the use of Agent Orange herbicide during the war was undertaken to begin the process of investigating the above noted relationships. The assessment also included recommendations related to environmental impact mitigation and rehabilitation components.

The study was undertaken in the Aluoi Valley, central Viet Nam (Plate1.1; note barren hillsides - most noticeable in right photo panel; Plate 1.2) to assist with the environmental rehabilitation process in Viet Nam and provide information to complement efforts of Vietnamese medical doctors and scientists involved in human dioxin contamination studies. The initiation of systematic environmental investigations of dioxin contamination of Viet Nam food chain components complements ongoing Vietnamese epidemiological work related to the Agent Orange issue. The study is relevant to assessing impacts on human health due to dioxin exposure in Viet Nam on:

- the general Vietnamese population (first, second, and third generation subsequent to the war);
- Ranch Hand (U.S. Forces) herbicide spray application personnel; and

- ground troops (U.S., Australia, New Zealand, Korea, North and South Viet Nam, Thailand, Philippines).

Results of this work are also relevant to the interests of environmental and human health agencies in many other parts of the world who are concerned with the effects of environmental dioxin contamination on human health.

PROJECT TEAM

The project was carried out by members of Hatfield Consultants Ltd., a Canadian environmental consulting company, and the Vietnamese 10-80 Committee, a government agency established in October 1980 to investigate the consequences of the chemicals used during the Viet Nam war on human health and the environment. Hatfield staff consists of environmental biologists and chemists with inter-disciplinary experience in carrying out environmental assessment projects in Canada and Asia. Hatfield has been carrying out dioxin environmental contamination studies in Canada for approximately ten years. The company is based in West Vancouver and has offices in Indonesia and Thailand.

The 10-80 Committee consists of medical doctors and chemists who, since 1980, have been carrying out studies on human health problems that appear to be related to Agent Orange use during the war. The 10-80 Committee staff was augmented during field work components of the study by members of the Vietnamese Forest Inventory and Planning Institute (FIPI) and by staff from the provincial Departments of Health from the heavily sprayed areas assessed by the project team. The 10-80 Committee has previously collaborated with Japanese, French and American investigators who also have carried out some preliminary work related to determining levels of Agent Orange dioxin contamination, mainly in human populations in Viet Nam.

The project team included the following personnel.

Hatfield Consultants Ltd.

Chris Hatfield, M.Sc.	Canadian Project Director
Wayne Dwernychuk, Ph.D.	Canadian Project Manager, Senior Ecologist
Dave Levy, Ph.D.	Ecological Specialist
Grant Bruce, M.Sc.	Environmental Chemistry Specialist
Thomas Boivin, M.Sc.	Dioxin Sampling Specialist
Martin Davies, M.E.S.	Remote Sensing Specialist
Andrew Allan, B.A., Post Dip. N.R.M.	Dioxin Field Sampling Specialist
Alex Sartori, Dip. Tech.	Dioxin Field Sampling Technician
Norm Sloan, Ph.D.	Editorial Support
Nguyen Luong Bach, Ph.D.	G. I.S. Specialist

10-80 Committee

Hoàng Dình Câu, M.D.	Vietnamese Project Director
Hoang Trong Quynh, M.D., Ph.D.	Vietnamese Project Manager
Ngugen Huu Duc, Ph. D.	Fisheries Specialist
Phung Tri Dung, M. D.	Field Sampling Assistant/Coordinator
Le Cao Dai, M.D.	Project Advisor
Vu Duc Thao, Ph.D.	10-80 Analytical Laboratory Chemistry Specialist
Lê Hong Thom, M.D.	Project Coordinator
Phung Tuu Boi	Forestry Specialist
Tran Thanh Xuan	Project Coordinator
Le Huy Hoang	Project Assistant

This report has been prepared as a summary of the study team's environmental assessment activities between 1994-1998, and has been prepared for circulation and distribution to all interested parties.

2 STUDY APPROACH AND OBJECTIVES

The Hatfield/10-80 Committee study described in this report was carried out from 1994-1998. Four basic approaches were undertaken during the study:

- reconnaissance site visits to areas subject to war-time impacts;
- literature review related to Viet Nam war activities, environmental resource information and previous dioxin contamination work;
- an Aluoi Valley dioxin contamination pilot study and Ma Da Forest spot-check assessment; and
- a satellite remote-sensing survey of the most heavily sprayed areas utilizing new Canadian RADARSAT technology, supplemented by historic LANDSAT and SPOT imagery.

Figure 1.1 presents the herbicide spray missions in southern Viet Nam. Also shown are the areas selected for the dioxin and RADARSAT programs.

Specific objectives of the Hatfield/10-80 program included:

- to determine current concentrations of dioxins and furans in soils, sediments and biota in pilot areas of the Viet Nam environment;
- to compare soil/sediment/biota dioxin levels in areas of south Viet Nam which were heavily sprayed with defoliants during the war, with levels in unsprayed areas of northern Viet Nam; and
- to compare data on dioxin in the environment with other epidemiological work.

Execution of the study consisted of site visits, training sessions/workshops, information interviews, etc. Two sampling expeditions were carried out; the second being designed on the basis of data obtained from the first.

During the initial stages of this investigation, a number of visits to Viet Nam by Hatfield personnel were made between 1994 and 1995 in order to formulate a workable study design. With the support and participation of the 10-80 Committee in Ha Noi, and their satellite office in Ho Chi Minh City, members of the team visited Ca Mau, Ben Tre, Rung Sat, Quang Tri, Ma Da, Aluoi and Con Cuong. Discussions were held with government departments, local Peoples' Committees, and health services personnel in these regions to obtain a better understanding of local impacts of the war, general topography, habitats, potential logistical problems, etc. (i.e., general ecosystem configuration), and to obtain local permission to conduct sampling activities (Plate 2.1).

Interviews were held in Ha Noi to recruit personnel to work with the Hatfield/10-80 team. Training of Vietnamese counterparts in the collection/handling of materials for ultra-trace contaminant studies was an integral part of the project.

A total of five Vietnamese were brought to Vancouver, Canada in 1995 and 1996 for two weeks of technical familiarization within their respective areas of expertise (two medical doctors, one forestry specialist, one zoologist and one laboratory analytical specialist).

In mid-1995, it was decided that the Aluoi Valley was the most acceptable location for a pilot study considering the objectives of our program. Given the lack of industrialization in Aluoi, the importance of Aluoi as a major route along the Ho Chi Minh trail during the war, the high level of Agent Orange application, Aluoi's isolation and the basic agrarian nature of the local people, this region was deemed suitable for our investigation. Con Cuong was selected as the control area for the first sampling expedition which was carried out in early 1996.

Given the constraints of limited sampling power, it was critical that the data should not be compromised by confounding environmental variables. Dioxin analyses are very expensive (approximately $1,000 per sample). It was therefore important that the study be designed efficiently in order to maximize information content per analytical dollar spent. For this preliminary assessment, it was possible to analyze a total of 50 samples for dioxin. Samples collected but not analyzed were archived.

Prior to field collection activities in Aluoi, workshops were held in Ha Noi to review with 10-80 Committee members and other Vietnamese attendees, information on how studies comparable to the one being proposed for the Aluoi Valley have been executed in Canada (Plate 2.2). Sampling equipment, handling and storage protocols for ultra-trace contaminant studies and QA/QC methods were discussed. Use of Global Positioning System (GPS) devices was explained in conjunction with the critical need for accurate descriptive data to accompany field samples. It was conveyed to the team that during the actual field programs there was opportunity for those involved to become active in the collection and handling of samples with supervision by Hatfield staff. Methodology for dissection of biological tissues was also presented during the workshops.

The launch of the Canadian RADARSAT remote sensing satellite occurred in late 1995. It was anticipated that during our dioxin investigation, satellite imagery could be used in conjunction with Aluoi dioxin data to provide an additional tool to assess environmental impacts of the war.

Data on the Aluoi Valley were collected in order to provide comprehensive background information of the region and its people. Geography, soils, climate, biological systems and socio-economic conditions were described (Appendix A1) following site visits and extensive interviews with local residents and government officials. Video and still photography were used to document the current environmental setting and activities of the study team in the area (Plates 2.3 and 2.4). These data were summarized in a series of internal trip reports which assisted the study team to formulate appropriate sampling strategies.

A literature review was undertaken focussing on how herbicide spraying was undertaken, and previous work that has been performed in Viet Nam. This review is presented in Section 3 to orient the reader to dioxin related information.

A brief review of dioxins and furans was prepared (Appendix A3). It should be noted that Appendix A3 is not intended to serve as an exhaustive review on the subject. The literature on various issues related to dioxins is voluminous; the intent of Appendix A3 is simply to provide readers with a general overview of what is generally known regarding sources, levels, fate and toxicity of dioxins in the environment.

3 LITERATURE REVIEW – A FOCUS ON VIET NAM

HERBICIDE SPRAYING

"*The defoliants were a major factor in reducing the number of ambushes that were long so costly in American and South Vietnamese lives*" (Gen. W.C. Westmorland 1976).

After testing in 1961, aerial spraying commenced as Operation Ranch Hand in 1962, peaked between 1967 and 1969 and was terminated in 1971. More than 6,500 aerial spray missions are recorded in the HERBS data base maintained by the Chemical Operations Division, U.S. Military Assistance Command, Viet Nam, for the period of August, 1965 to February, 1971 (U.S. Institute of Medicine [IOM] 1994). This database contains dates, flight coordinates, amounts and types of herbicides sprayed.

Estimates of the amount of herbicides sprayed in southern and central Viet Nam from 1962 to 1971 vary. Only southern areas of Viet Nam, known in the war years as the Republic of Vietnam (south of the demilitarized zone - DMZ), were sprayed. A total herbicide volume of ~72 million litres has been widely cited (Westing 1984a; Cecil 1986; Spaeth 1994). This appears now to be an underestimate according to the U.S. National Academy of Science (NAS) (IOM 1994). The following table lists total herbicide and Agent Orange volumes.

Volume estimates of Agent Orange and total herbicides sprayed.

Reference	Data Source	Time Period	Agent Orange (Litres*) x 10^6	Total Herbicides (Litres*) x 10^6
Westing 1984a, p. 7	Westing 1976 (SIPRI volume)	1962-1971	44.3	72.3
Cecil 1986, Table 1, p. 231	Westing 1976 (SIPRI volume)	1962-1971	NS	72.3
Spaeth 1994, p. 35	NS	NS	42	NS
IOM 1994, Table 3-1, p. 77	HERBS tape	1965-1971	42.3	66.6
IOM 1994, p. 97	NAS additional estimate	1962-1971	NS**	9.1

* converted from U.S. gallons.
** 2.3 million litres confirmed as Agent Orange from Services HERBS database.
NS = Not Specified.

The final IOM (1994) estimate of ~20 million U.S. gallons (75.7 million litres) was based on the 1965-1971 HERBS tape plus 2.4 million U.S. gallons (9.1 million litres) estimated by the NAS from other sources; these other sources include the following:

- spraying before and after records on the HERBS database (i.e., from Spring 1962 to July 1965 and March 1971 to the end of spraying later in 1971);

- the Services HERBS database (IOM 1994; p. 98, Table 5-3) made by the U.S. Army Joint Services Environmental Support Group recorded an additional 1.6 million U.S. gallons of herbicide (= 6 million litres, of which 2.4 million were Agent Orange) from helicopter, backpack and other types of ground spraying from1962 to 1971; and

- the NAS estimated another 3 million litres of herbicides used for the final total of 9.1 million litres *not* represented on the HERBS database.

Also carried over from the HERBS database is the estimate that Agent Orange accounted for 60% of total herbicide volume. Approximately 11.3 million gallons or ~51.3 million litres of Agent Orange were sprayed during 4,109 of the missions recorded in the HERBS database.

Approximately 34% of the target areas were sprayed more than once and some areas, especially upland forests, were sprayed up to four times. Herbicide spraying recorded in the HERBS database calculated ~ 3.6 million acres (~1.5 million ha), an area equivalent to ~10% of South Viet Nam (Bengtsson 1976; Cecil 1986; IOM 1994). Most areas sprayed were inland and mangrove forest; however 14% of spray missions targeted cropland comprising 177,000 ha of upland crops and 59,000 ha of rice paddy (World Bank 1995b).

Two ecologists wrote a vivid account of a spray mission (Neilands *et al.* 1972):

"The target area [in the Plain of Reeds] *was marked by smoke bombs, and we dove from our altitude of 4,500 feet to about 100 feet above the ground at the maximum descent allowable by the aircraft. There were seven aircraft in our flight, and they were staggered so that the spray from each plane overlapped the spray from the plane ahead of it. As we leveled off, one could see the spray emerging from the nozzles on the wings and the tails of the planes ahead of us. From our location between the pilot and the copilot we were able to see the operation readily. As we flew just above tree level, hundreds of herons, egrets and storks flew up in front of us and we may have hit some of these birds as we flew through them. At the beginning of the run our escort of F-100 fighter-bombers, going at tremendous speed, dropped cluster bomb units on either side of the target area. These produced large explosions and clouds of smoke in our path. The subunits then exploded in smaller balls of red fire looking like sparklers and spreading the antipersonnel pellets designed to keep down the heads of the antiaircraft gunners below us."*

The associated physical damage to habitats and wildlife from the air attacks, undertaken to protect aircraft while spraying, is undocumented.

HERBICIDE CHEMICALS

The main chemicals used as defoliants and for crop destruction are listed below.

Major herbicides used in Operation Ranch Hand (from IOM 1994, Table 3-4, p. 89).

Herbicide	Formulation	Purpose	Litres Sprayed ($x10^6$)	Period of Use
Agent Orange, Orange II	2,4-D; 2,4,5-T	General defoliation	42.62	1965-1970
Agent Purple	2,4-D; 2,4,5-T	General defoliation	0.55	1962-1964
Agent Blue (Phytar 560G)	Cacodylic acid	Rapid defoliation, grassy plant control, rice destruction	4.25	1962-1971
Agent Pink	2,4,5-T	Defoliation	0.46	1962-1964
Agent Green	2,4,5-T	Crop destruction	0.03	1962-1964
Agent White (Tordon 101)	2,4-D; picloram	Forest defoliation, long-term control	19.85	1965-1971

Note: Text under the heading "Military Herbicides" (IOM 1994) describes chemical make up and proportions.

Agent Orange was a mixture of 2,4-D (2,4-Dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-Trichlorophenoxyacetic acid). 2,3,7,8-Tetrachlorodibenzo-para-dioxin was found to be a contaminant present in the herbicide mixture. According to one of the manufacturers of Agent Orange, Dow Chemical, levels of dioxin varied from <0.05 ppm to ~50 ppm (IOM 1994). According to Gough (1986), ~ 90% of all Agent Orange was sprayed on jungle, ~8% on food crops and ~2% was used by other branches of the military for special purposes.

Dioxin concentrations in Agent Orange stocks remaining after the war ranged from 0.05 to ~50 ppm and averaged 1.98 to 2.99 ppm for two sets of samples that were analyzed (IOM 1994). Applying an average dioxin concentration of 4.0 ppm for the 72 million litre volume estimate (from the HERBS database), results in an approximate pure dioxin loading to Viet Nam of ~170 kg, as reflected in the popular literature (Westing 1984a; Spaeth 1994). Bengtsson (1976) provided a higher estimate of the average dioxin content of herbicides used in Vietnam at ~16 ppm.

Agents Pink, Green and Purple contained dioxin at mean concentrations estimated to be 65.6 ppm, 65.6 ppm and 32.8 ppm, respectively (IOM 1994). None were used after 1965.

To place the above dioxin concentrations in context, it is useful to compare levels of dioxins in pulp mill effluents to the Agent Orange concentrations. Dioxin concentrations in these effluents are typically expressed in units of pg/L or parts per quadrillion (ppq -i.e., one part per 10^{15}). This can be compared to dioxin concentrations in Agent Orange that were expressed in units of parts per million (ppm - i.e., one part in 10^6). The dioxin concentrations in Agent Orange were in the range of a billion (10^9) times more than dioxins in pulp mill effluents. In the early 1990's most health and environmental jurisdictions were requiring major reductions in pulp and paper mill effluent dioxin levels to meet new regulations. Hatfield dioxin monitoring work related to this process in British Columbia is included in reports listed in Appendix A3 (see Dwernychuk *et al.* 1989 to 1998 in Appendix A3).

Dioxins and Furans

Dioxin compounds became more widely known in the late 1970s, given that improved analytical technologies revealed these substances were ubiquitous environmental contaminants that could be detected in samples collected from non-industrialized areas. Many different species, including humans, may contain measurable concentrations of dioxins. Many U.S. veterans of the Viet Nam war became convinced that dioxin levels in Agent Orange were causing health effects.

> *"I too am convinced, based on what I have read, and conversations with people, that Agent Orange can cause cancer and birth defects, and in the case of many Viet Nam veterans, has done precisely that. I realize the final scientific word is not in yet, but I think that because of all the veterans Elmo and I contacted, and all the illnesses and medical problems they told us about, we are ahead of the scientific evidence"* (Zumwalt and Zumwalt 1986).

Public concerns regarding the potential impact on human health in particular, and the ecosystem in general, intensified. For example, the popular press (TIME magazine) labeled dioxin "*one of the most potent poisons known to man*" (Spaeth 1994). A recent article in the Economist (July 25, 1998) discusses toxic dioxin emissions in Japan, and the public outcry for regulatory action. Investigations occurred world-wide on the origin, distribution, transformation, accumulation, and toxicity of dioxin and related chemicals (NATO 1988a,b,c). Appendix A3 provides general background information on dioxins and furans.

Structure of Dioxins and Furans

Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) consist of a series of almost planar tricyclic aromatic compounds that can be chlorinated in a variety of positions. Dioxins and furans can be substituted with one to eight chlorine atoms. This gives rise to 75 different chlorinated dioxins and 135 different chlorinated furans. The toxicity of PCDD and PCDF is dependent on the degree of halogenation, and on the location of the halogen atoms. The most toxic dioxin (the one commonly called "dioxin" by the popular press) is substituted with four chlorine atoms attached at the 2,3,7,8 positions, and is therefore referred to as 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin or 2,3,7,8-T4CDD (often it is abbreviated further to TCDD). It is considered to be less toxic to humans compared to a number of other animal species (CADAS 1994).

Toxicity Equivalency Factors (TEFs) and Toxic Equivalent (TEQ)

Since the toxic effects of most dioxins and furans are similar, but vary greatly in degree, an internationally accepted method for expressing the toxicity of different dioxins and furans on a common basis has been developed (NATO 1988a,b). Toxic Equivalency Factors (TEFs), determined through experimentation, have been assigned to individual dioxins and furans on the basis of how toxic they are in comparison to the toxicity of 2,3,7,8-T4CDD, the most potent dioxin. 2,3,7,8-T4CDD has been assigned a TEF value of 1. By comparison, and as an example, research has determined that 1,2,3,7,8-Pentachlorodibenzodioxin is approximately half as toxic as 2,3,7,8-T4CDD and consequently has a TEF of 0.5.

A toxic equivalent (TEQ) of a mixture of congeners can be obtained by adding together the concentrations of various dioxins and furans multiplied by their respective TEFs. In general, dioxins and furans that are substituted in the 2,3,7,8 positions are the most toxic and have 2,3,7,8-T4CDD-TEQ values in the range of 0.001 to 0.5. Of the 210 possible dioxins and furans, the 17 listed in the following table are believed to contribute most to the toxicity of a mixture of dioxins and furans.

Dioxin and Furan Toxicity Equivalency Factors (TEFs) (NATO 1988a).

Dioxin/Furan	Equivalency Factor	Dioxin/Furan	Equivalency Factor
2,3,7,8-Tetrachloridibenzodioxin	1.0	1,2,3,7,8-Pentachlorodibenzodioxin	0.5
1,2,3,4,7,8-Hexachlorodibenzodioxin	0.1	1,2,3,7,8,9-Hexachlorodibenzodioxin	0.1
1,2,3,6,7,8-Hexachlorodibenzodioxin	0.1	1,2,3,4,6,7,8-Heptachlorodibenzodioxin	0.01
Octachlorodibenzodioxin	0.001	2,3,7,8-Tetrachlorodibenzofuran	0.1
2,3,4,7,8-Pentachlorodibenzofuran	0.5	1,2,3,7,8-Pentachlorodibenzofuran	0.05
1,2,3,4,7,8-Hexachlorodibenzofuran	0.1	1,2,3,7,8,9-Hexachlorodibenzofuran	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	0.1	2,3,4,6,7,8- Heptachlorodibenzofuran	0.1
1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.01	1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.01
Octachlorodibenzofuran	0.001		

Total-TEQ value for a single sample is the sum of all the "normalized" concentrations and should be viewed only as a summary statistic to assess total contamination. In the calculation of a Total TEQ, where a ND (non detect) is registered for a given congener, it is customary to include 50% of the corresponding detection limit in the summation; although it has also been suggested that 100% of the detection limit could be used (Schecter 1994a).

Unlike 2,4-D and 2,4,5-T, which break down over a period of months, dioxin (the 2,3,7,8 congener) is a relatively stable compound persisting in the environment (IOM 1994). The estimated half-life of dioxin in the environment ranges from 3.5 years (Westing 1984a) to ten years (Thu *et al.* 1994).

HERBICIDES AND HUMAN HEALTH

"*Few issues manifest the ideological divisions in our society as powerfully as the Vietnam War, and no public health issue is more entangled with our unease about that war than the health effects of dioxin*" (Dwyer and Flesch-Janys 1995).

"*Although the focus began with war, the question is now one of chemicals and health, how to use them to help all people without harming them. Long-term consequences for the health of all* *people from synthetic chemicals has become the common battleground for future cooperation, between peoples and between nations"* (Cau *et al.* 1994a).

General Concerns over Human Health

The human health-related literature on Agent Orange and herbicide spraying in Viet Nam includes books (Whiteside 1971; Wilcox 1983; Westing 1984b; Cecil 1986; Gough 1986; Schuck 1986; Young and Reggiani 1988; IOM 1994), an annotated bibliography on Agent Orange (Harnley 1988) and specifically on dioxins (Rappe *et al.* 1986; Schecter 1994a,b).

Chlorinated dioxins are fat-soluble chemicals which can be transported progressively up the food chain to humans (CADAS 1994), and are readily stored in the lipids of human fat (adipose tissue) breast milk, and in blood (Schecter 1994a,b). Intoxication is possible by direct exposure or through eating contaminated food, such as fish (Svensson *et al.* 1991) or breast milk. Further, dioxins are magnified in the food chain (CADAS 1994; IOM 1994), of which humans are an end point. Human tissue concentrations have half life estimates ranging from five to eleven years (Schecter 1994b; Dwyer and Flesch-Janys 1995).

The medical effects of dioxins and whether or not dioxins are a human carcinogen is a controversial topic. In one of the few studies of direct exposure, Zober *et al.* (1990) studied 247 workers who were exposed to dioxins in a 1953 accident at a chemical plant. They reported only a slight increase in mortality resulting from cancer. They subsequently selected a subcohort of individuals on the basis of test subjects who had developed chloracne (therefore indicative of high exposure); a two-fold increase in cancer mortality was detected in this subcohort investigation. In addition to the above study, Dwyer and Flesch-Janys (1995) also summarize other epidemiological studies involving exposure of chemical workers to TCDD; they state that "these epidemiological findings are thus consistent with the animal data indicating that TCDD is a potent carcinogen at multiple sites across mammalian species".

In 1993, the U.S. Environmental Protection Agency concluded after a general reassessment of dioxins that exposure is associated with "subtle biochemical and biological changes whose clinical significance is as yet unknown" (Anonymous 1994). A French national team (CADAS 1994) stated that given we have the means to identify and control the risks associated with dioxins, in conjunction with the relatively small amounts involved, "these substances do not pose a major public health problem". They also state that "the value of 10 pg/kg/day established by the World Health Organization is an acceptable daily intake of PCDD/F for human organisms, today seems a realistic and sensible guide. It should be retained as a means of managing the public health risk of dioxins".

DeVito and Birnbaum (1994) stated that "the available data indicate that humans are sensitive to the toxic effects of these chemicals [dioxins]". Kerkvliet (1994) indicates there is a general acceptance that dioxins (TCDD) "alter multiple cellular targets within the immune system".

The relationship between dioxin and human health remains controversial; researchers also tend to agree that more studies are required in order to generate a clearer understanding of the effects of TCDD on humans.

In Canada, federal legislation governing dioxin/furan releases into the environment became law in 1992 (CEPA 1992). By 1994, all pulp mills in Canada were releasing final effluents with virtually non-measurable concentrations of 2,3,7,8-T4CDD or 2,3,7,8-T4CDF. Costs to the British Columbia pulp and paper industry alone of this dioxin cleanup from pulp mill effluent exceeded $2.2 billion between 1988 and 1993 (MOE 1994). The speed at which government and industry reacted to address the dioxin/furan contamination problem in Canada indicates the perceived health hazard that dioxins and furans pose to the environment and human health.

Medical studies have attempted to evaluate health effects of dioxin contamination associated with herbicide spraying during the Viet Nam war. Two main areas of investigation have been the primary focus:

- U.S. Viet Nam veteran health issues associated with military personnel who, through various means, came into contact with herbicides; and
- preliminary epidemiological studies in Viet Nam which evaluated the effects of spraying on Vietnamese exposed during the conflict.

In 1991, the U.S. Secretary of Veterans Affairs requested the U.S. National Academy of Science to conduct a major review of health effects on U.S. veterans exposed to Agent Orange and other herbicides used in the Viet Nam war. A review of the scientific data was undertaken during which the committee weighed these data from the perspective of inherent strengths and limitations – essentially a weight of evidence approach. The resulting report by the Institute of Medicine (IOM 1994) concluded that there is sufficient evidence for an association between Agent Orange exposure and several medical conditions, including soft tissue sarcoma, non-Hodgkin's disease, Hodgkin's disease, chloracne, and porphyria cutanea tarda (PCT; a thinning and blistering of the skin when exposed to the sun). The report also concluded that there was limited/suggestive evidence of an association between Agent Orange exposure and respiratory cancers (lung, larynx and trachea), multiple myeloma (bone marrow cancer), and prostate cancer.

The U.S. Institute of Medicine in their 1996 update (IOM 1996), has determined that there is "limited/suggestive evidence of an association between" Agent Orange exposure and the birth defect spina bifida and peripheral neuropathy (acute and subacute); the latter condition being a nerve disorder which can cause pain, numbness and weakness in limbs. The 1996 IOM document also downgraded PCT from "sufficient evidence" to "suggestive evidence' of a relationship to Agent Orange.

Dioxin Levels in the Vietnamese

Schecter *et al.* (1995) stressed that because of the amount and duration of herbicide spraying and number of victims exposed, Viet Nam is the best place in the world to study dioxin effects in human populations. Verger *et al.* (1994) point out that in Viet Nam, a sound "exposure index" is in hand, based on the HERBS database and questionnaire responses on villagers' place and duration of residence. This index can be correlated with dioxin levels which persist in human fat. It is ironic that dioxin levels in Ha Noi residents were the lowest of any worldwide urban population studied (Schecter *et al.* 1986). This was attributed to the region's low level of industrialization from which human dioxin levels may develop (Appendix A3). An example of blood dioxin levels from industrialized nations (e.g., U.S.), unindustrialized areas (e.g., northern Viet Nam) and herbicide-sprayed areas (e.g., southern Viet Nam) is illustrated in Figure 3.1.

It is known that dioxin has been taken up into tissues of Vietnamese exposed to Agent Orange (Schecter *et al.* 1986; 1989a). Schecter *et al.* (1995) reported dioxin levels as high as 1,832 ppt* from human milk collected in southern Viet Nam in 1970 and levels up to 103 ppt in adipose tissue in the 1980s. Verger *et al.* (1994) described a correlation between dioxin levels in adipose tissue and estimated exposure to Agent Orange in south Vietnamese residents. The Government of Viet Nam, through the 10-80 Committee, is actively involved in preliminary epidemiological studies of the health effects of dioxin contamination (Cau *et al.* 1994a).

The 10-80 Committee studies have yielded some important generalizations. Pooled blood dioxin levels of people in the sprayed south are generally higher than those of people in the (non-sprayed) north. The same geographic trend is seen in human breast milk (Figure 3.2).

Dioxin levels in human fat show a similar trend. Schecter (1994b) reported 1.4 ppt from a pooled sample of ten permanent Ha Noi residents, versus 8.1 ppt from a pooled sample of ten veterans then living in Ha Noi, but who were exposed to Agent Orange when they fought in the south over 20 years previously. It is noteworthy that these figures arose from studies undertaken after 1987, indicating that human tissue dioxin levels persist and remain relatively high for Vietnamese first exposed between 1962 and 1971. Persistent dioxin contamination is also supported by the likelihood that some second generation (and possibly third generation) Vietnamese born after the war are experiencing medical problems possibly attributed to dioxins (Schecter *et al.* 1995; Pearce 1998).

Other generalizations from a 1993 Ha Noi conference on herbicides used during the war reported in Cau *et al.* (1994a) are:

- tissue dioxin levels are positively correlated with amount of exposure such as residence times in sprayed areas and the amount of spraying that occurred there (Dai *et al.* 1994a);
- dioxin levels increase in people with increasing age – indicating chronic absorption from contaminated environments or food (Phiet *et al.* 1994);
- the persistent use by farmers of organochlorine insecticides such as DDT and HCH does influence current levels of chloro-organic compounds in Viet Nam, especially important as an artifact in dealing with the issue of food contamination;

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*ppt (parts per trillion) = pg/g (picograms per gram); these units are interchangeable.

- the food chain is a probable vector for human uptake (Quynh *et al.* 1994);
- chronic contamination of people occupying contaminated locations remains a concern (Quynh *et al.* 1994); and
- tissue dioxin levels decrease over time, as shown in the human milk data in the following table (Quynh *et al.* 1994).

2,3,7,8-T_4CDD (ppt, lipid basis) in individual and pooled human milk samples from Tan Uyen village, in a heavily sprayed part of Song Be Province, southern Viet Nam from 1970 to 1988; data from Schecter *et al.* (1994b).

Single Sample	3 Individual Analyses			3 Pools of N = 2		
1970	1973			1985 – 1988		
1,450 ppt	77 ppt	100 ppt	230 ppt	2.9 ppt	5.2 ppt	11 ppt

Numerous papers in Cau *et al.* (1994a) associate dioxin (Agent Orange) contamination with chronic human health issues, for example:

- births in heavily sprayed area (Song Be Province) yielded high rates (2.8%) of congenitally malformed babies (Yamamoto *et al.* 1994);
- sprayed villages showed higher rates of infant mortality (Dai *et al.* 1994b);
- families of veterans exposed to herbicides had increased rates of abnormal pregnancies and birth defects (Dai *et al.* 1994b);
- some indication of immuno-suppression in sprayed people (Dau *et al.* 1994); and
- Harada *et al.* (1994) discounted both the possibilities that dioxins persisting in the environment and dioxins persisting in people were the causes of congenital diseases; rather, they concluded that dioxin-related congenital malformations resulted from damage caused years ago at the time of historical exposure.

Although the above noted effects have been associated with Agent Orange exposure, these results require confirmation studies by multinational medical/environmental teams.

Another series of papers on chronic health issues among Vietnamese came from the Joint Vietnam-Russia Tropical Research Centre, Ha Noi and were published in the 15th International Symposium on Dioxins in 1995. Some of their findings among villagers from heavily sprayed areas were:

- infectious respiratory diseases and certain "sub clinical" pathological conditions might occur as long-term consequences of exposure to Agent Orange (Poznyakov *et al.* 1995);

- apparent inability to repair cell loss in the buccal mucosa (mouth lining) tissues (Oumnova *et al.* 1995a; Zhuleova *et al.* 1995);

- increased incidence of congenital malformations and stillbirths, and indications of alterations in genetic material (Oumnova *et al.* 1995b); and

- "significant subjective outcomes associated with a history of direct contact with Agent Orange" (Roumak *et al.* 1995); this came from generalizations on villagers' well-being from evaluating questionnaire-derived characteristics of toxic responses.

The last paper demonstrates how difficult it would be to rely on such work done 15 years after the war.

ENVIRONMENTAL IMPACTS OF WAR-RELATED HERBICIDES IN VIET NAM

Early opinions on the environmental impacts of herbicides vary. For example, Gen. William C. Westmorland, Commander, U.S. Military Assistance Command, Vietnam (COMUSMACV) from 1964 to 1972 was vaguely dismissive:

"*Some ecological damage may have resulted from the defoliants; how much and how permanent it is remains to be seen. Flying over much of the country as recently as 1972, I found Vietnam still a verdant land, which left me to question the truth of some of the more pessimistic allegations of permanent damage*" (Westmorland 1976, p. 280).

Others were more forthright. Neilands *et al.* (1972) quote Brig. Gen. W.W. Stone (Director, U.S. Army chemical/nuclear operations) speaking from retirement in the early 1970s:

"... our use of herbicides has not created any permanent ecological damage of any significance in Vietnam."

Neilands *et al.* (1972) also quote K.W. Thimann, a herbicide specialist and American Association for the Advancement of Science board member who said in 1968 that the Army's use of herbicides for defoliation:

" ... probably represents a military device for saving lives that has an unprecedented degree of harmlessness to the environment."

On the other hand, Professor Vo Quy (Director of the Centre for Natural Resources Management and Environmental Studies, University of Ha Noi) stated that the U.S. military's use of herbicides resulted in the destruction of a significant proportion of tropical forest and agricultural land (Quy 1992 and *pers. comm.*). Herbicide impacts, in conjunction with use of bulldozers, napalm and saturation bombing resulted in the loss of an estimated 20 million cubic metres of timber, 300 million kg of food, 135,000 ha of rubber plantation and the elimination of much of southern Viet Nam's wildlife and fisheries (Quy 1992).

A generation after the war, the World Bank stated:

"*One of the least understood and potentially most detrimental aspects of the war is how the modification in species distribution that it caused may have permanently changed the biodiversity of Viet Nam*" (World Bank 1995b).

Ecological Effects

Preliminary Concerns and Opinions

Initial environmental impact assessments associated with herbicide spraying and defoliation began during the war (Tschirley 1969; Orians and Pfeiffer 1970). These assessments were, in part, driven by serious misgivings regarding the ethics of chemical warfare as well as concerns regarding unknown ecosystem impacts. Technically, these early assessments evaluated the impact of defoliation and, in particular, the toxic effects of the herbicide constituents on forests and crops. At the time of these early assessments, many of the environmental/health effects of dioxin contamination were unknown.

The Society for Social Responsibility in Science funded a March 1969 trip of biologists to learn about the effects of defoliants (Orians and Pfeiffer 1970; Neilands *et al.* 1972). One of their field trips, for example, was to Rung Sat near Ho Chi Minh City. They concluded that the Rung Sat mangroves were "extremely susceptible" to defoliants. Only one application was apparently necessary to "kill most trees". Most of the areas they visited remained "completely barren" although they had been sprayed several years earlier. They speculated that:

"*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.*"

Plate 3.1 is an aerial view of lush mangrove forests in southern Viet Nam; this area was not sprayed with herbicides during the war. Plates 3.2, 3.3 and 3.4 show the effect of herbicide spraying on mangrove forests several years subsequent to herbicide applications (also in southern Viet Nam).

Other concerns were expressed by biologists regarding possible long-terms direct toxic herbicide effects and indirect ecosystem effects as follows:

"*The defoliation program has caused ecologic changes. I do not feel that the changes are irreversible, but complete recovery may take a long time. The mangrove type is killed with a single treatment. Regeneration of the mangrove forest to its original condition is estimated to require about 20 years*" (Tschirley1969; Neilands *et al.* 1972); and

"*.... it may take decades for some of the damaged* [upland] *forest lands to recover, partly because the invading bamboo and grasses may be difficult to eradicate, and partly because* *nutrient minerals previously tied up in forest vegetation may have been released and then leached out of sprayed forests by heavy tropical rain"* (Boffey 1971).

Shortly after the war, Bengtsson (1976) identified two immediate research initiatives required in Viet Nam:

- to document the presence of toxic effects and how remediation should proceed; and
- to determine the best land uses for damaged areas and develop restoration/regreening options.

Vietnamese Response to Ecological Effects

"This re-greening effort is the biggest challenge facing the country since its reunification in 1975" (Quy 1992).

In October 1980, the Government of Viet Nam established the "10-80 Committee" to execute a national research program investigating the long-term effects of war-time herbicides on the environment and human health and to develop remediation measures. The Committee hosted two international conferences on the long-term environmental and human health impacts of the war in 1983 and 1993 (Cau *et al.* 1994a). There has been a significant in-country effort to assess and remediate chemical war-associated damage to forests with the following objectives as reported in FIPI (1991):

- identify affected areas;
- assess changes to damaged forest ecosystems;
- assess natural regeneration; and
- assess prospects of, and methods for, reforestation of damaged areas.

The environmental consequences of the war remain an important domestic Vietnamese issue and a major research area within the 1991 National Plan for Environment and Sustainable Development of Viet Nam (Can 1992). Nation-wide deforestation, caused in part by the war, has reduced total forest cover from ~44% in 1943 to <25% of the total land area at present, including a high proportion of "bare" land accounting for ~37% of the land area (GOVN/GEF 1994).

There are generalizations on residual herbicide impacts on Vietnamese forest ecosystems (Ashton 1986; FIPI 1991; Quy 1992; Hong and San 1993; Boi and Cham 1994; Ha and Boi 1994; Hong *et al.* 1994), for example:

- trees vary in susceptibility, but all forest types have susceptible species with particularly high proportions of species in mangrove and *Melaleuca* forests;

- spray-resistant trees such as *Irvingia malayana* and *Parinari annamense* were among the only large living trees in some areas;
- invasion of opportunistic species such as bamboos and grasses hamper natural reforestation by their thick ground cover and ultimately change forest composition;
- these new grasslands increased the incidents of wild fires, particularly during the dry season, that killed tree seedlings which greatly slowed or prevented reforestation;
- forest wildlife were killed or migrated from damaged forests;
- the destruction of forest wildlife, including predators, led to rat population explosions that spread diseases to people and damaged crops;
- leaf-drop from defoliation of mangroves provided a short-term pulse of organic matter into local food webs but also increased local biological oxygen demand (BOD) and increased turbidity that reduced phytoplankton growth;
- damaged hydrological characteristics of forests caused decreased water retention properties and increased severity of droughts and flooding;
- exposed topsoils eroded, especially during wet season rains;
- exposed mangrove soils experienced increased temperatures, higher evaporation, higher rates of oxidation, desiccation and pH changes towards acidic sulfate conditions;
- regeneration in unflooded mangrove areas has lagged badly behind flooded mangrove areas which were the preferred areas for reforestation; and
- defoliated mangrove areas permitted easier access, often leading to overharvesting of wood.

Dioxin Contamination

Studies have investigated the impacts of herbicide applications on individual Vietnamese ecosystem components such as soils. There is little information on the fate and effects of dioxin moving through different ecosystem components, or estimations of bioaccumulation in ascending trophic levels. Understanding these relationships would permit improved estimates of persistence and accumulation of dioxins in the environment and food chains leading to people. The Vietnamese government recognizes that it is necessary to do an integrated environmental evaluation of dioxin contamination, especially since the food chain is perceived as a probable vector for dioxin contamination of the human population in Viet Nam (Quynh *et al.* 1994).

Water

Huy *et al.* (1994) claimed that people could take up dioxin from drinking contaminated ground water; this has not been demonstrated in Viet Nam as it has in Europe. Groundwater dioxin levels remain an important missing data set for Viet Nam.

Soils and Sediments

The World Bank (1995b) pointed out that longer-term concerns regarding herbicide effects on agriculture revolve around herbicide persistence and mobility in the soil. As with other environmental aspects of the dioxin literature, opinions vary and definitive work is yet to be performed. The World Bank (1995b) concluded that "environmental insignificance" (i.e., lack of effect on all but the mostly highly sensitive of subsequently planted species) was reached within two months for the active ingredients in "all herbicides used during the war."

During the mid-1980s, sediment samples from the Dong Nai River, a heavily sprayed area, contained elevated dioxin levels compared to sediment samples taken from an unsprayed reference area, the Red River near Ha Noi (Schecter *et al.* 1989b). Matsuda *et al.* (1994) concluded from a soil survey of seven sprayed southern Viet Nam sites that, contrary to their expectation, dioxin concentrations were detectable (>1.0 pg/g) at only four sites. Further, dioxins occurred in the top 10 cm of soil. In the best sample series, 14 of 54 samples from Tay Ninh province exhibited readings ranging from 1.2 to 38.5 pg/g. Some values, therefore, exceeded the Matsuda *et al.* (1994) theoretical contamination level of 25 pg/g. They speculated that the higher values were attributable to lower rates of erosion in contaminated areas and that leaching had likely occurred in areas which had undetectable dioxins. Quynh *et al.* (1994) reported that dioxin residue levels persisted in coastal, highland and delta soils. They speculated that on-going contamination was possible for animals occupying contaminated areas, but provided no verification.

Terrestrial Flora excluding Forests

Quynh *et al.* (1994) speculated that dioxin levels are currently below detection in plant tissues. There is, however, no systematic study in the literature on wild plant contamination levels in Viet Nam.

Aquatic Ecosystems and Fisheries

"....coastal mangrove forests were considered to be the most heavily devastated by the wartime herbicide operation" (Snedaker 1984).

The contiguous aquatic ecosystems of sprayed forests received appreciable levels of herbicide contamination. Snedaker (1984) speculated there was a "good probability" that waters received direct and indirect herbicide loadings exceeding the equivalent loadings of sprayed forest areas because of water run-off, erosion, tidal mixing and bed-load transport of contaminated sediments. There remains, however, a lack of direct evidence on the probable effects of herbicides on estuarine and marine biota compared to that from forested environments (Snedaker 1984). The relatively low water solubility of herbicides means that their indirect input into aquatic ecosystems is dominated by sedimentation from run-off. Snedaker (1984) stressed that there were few data on residual herbicides or their breakdown products in aquatic sediments that would permit conclusions regarding sediment-related contamination in Viet Nam.

Coastal deltaic ecosystems, especially mangrove-associated, are better understood than freshwater ecosystems, for which baseline data are poor (Snedaker 1984). Damage estimates to terrestrial and mangrove forests tend not to include assessment of their associated aquatic ecosystems (Snedaker 1984). Yen (1994) outlines the food web and a trophic level description of three aquatic ecosystems in sprayed areas; however, this work has not been integrated with complimentary chemical analyses of local water, sediment and organism tissue.

"There are essentially no data available upon which estimates can be developed for determining the impact on these water areas" (Snedaker 1984).

Reports from freshwater ecosystems in the Aluoi Valley, cited by Snedaker (1984), revealed a correlation between spraying and decreased overall species diversity and morphological abnormalities in freshwater algae. There is no evidence that these were attributable to persisting toxicity of herbicides or their residues because of the variety and magnitude of other coincident environmental abuses during the war such as bombing (Snedaker 1984), and post-war from agricultural practices and population growth. Further, there remains the historical lack of complimentary chemical analyses as mentioned above.

The marine ecosystems of interest are associated with mangrove forests. Coastal fisheries productivity is linked, in part, to the well-being of these ecosystems. Owing perhaps to a pulse of organic material from fallen leaves, there was an apparent increase in fishery yields after spraying, followed by decreasing yields. Loss of productive estuarine habitat that supports fisheries, attendant changes in the physical environment (e.g., through erosion of denuded wetlands) and possible herbicide contamination have been considered to be responsible for the decline (Snedaker 1984). However, pre-war fisheries catch and effort data are poor and do not provide a reliable baseline for post-war comparison (Snedaker 1984). Moreover, current data on fish yields and practices remain inadequate for drawing such conclusions. Fisheries declines until at least the mid 1980s are still attributed to war damage of estuarine and mangrove habitats (World Bank 1995b), but remain poorly supported by environmental data. In addition, there has been relatively successful mangrove reforestation since the war; sprayed mangrove areas such as Rung Sat and Ca Mau are partially reforested (Hatfield Consultants Ltd. 1998) and are likely contributing to fisheries production.

High levels of dioxin were measurable in both fish and shellfish tissues within southern Vietnamese rivers and coastal areas in the early 1970s (Anonymous 1974). Cau *et al.* (1994b) reported levels of up to 60 ppt in wild turtle tissues collected in 1988. Linkages between these values and the well-being of aquatic ecosystem remain speculative.

Wildlife, Livestock and Human Food

Dioxin levels in animal tissues are suggested as being low (Quynh *et al.* 1994), however, as with plant tissue levels, there are no systematic, long term data on Vietnamese wild fauna and farm animals.

Dai *et al.* (1994c) and Cau *et al.* (1994b) reported on human food species (fish, chicken, pork) in which they stated that, by 1988, dioxin levels had decreased significantly and were considered comparable to foodstuffs in other nations. Both Dai *et al.* (1994c) and Quynh *et al.* (1994) contend that residual environmental contamination nonetheless remains a threat to human health. As with the other ecosystem components above, these generalizations suffer from a lack of integrated ecosystem studies. Further, the sample sizes of these studies have been relatively small due, in part, to the high cost of dioxin analyses.

4 ALUOI VALLEY DIOXIN ASSESSMENT

INTRODUCTION

Hatfield Consultants Ltd. has been monitoring dioxin contamination in Canada over the last ten years (see references in Appendix A3). A wide variety of environmental media have been collected and analyzed for dioxin/furan congeners. This experience has provided a solid base on which to plan and implement similar programs in Viet Nam.

Dioxins can be produced through a variety of processes and may be contained in materials as a bi-product of manufacturing or other processes. In order to minimize the impact of "confounding environmental variables" the Hatfield team visited a number of potential study regions in Viet Nam prior to selection of the primary study area.

The Aluoi Valley was selected as the pilot study area for the determination of dioxin residues (Plates 1.1, 1.2, 4.1 and 4.2) in environmental samples and human blood. The Aluoi Valley is situated approximately 65 km east of Hue. The U.S. military established a small airbase at A So (southern sector of the valley). The Aluoi Valley was considered a vital supply link to the south during the conflict. A So was a Special Forces base which was abandoned in 1966 (Cecil 1986; Summers 1995) (Plate 4.3). Spray missions in the Aluoi Valley extended over the period 1965-1970 (*pers. comm.* U.S. Dept. of the Army).

Black (1994) tabulates Agent Orange usage by province during the conflict (some names presented may not coincide with present provincial names). Black indicated that 47% of all Agent Orange used during the war was distributed in the ten provinces listed. Phuoc Long (present name primarily Song Be province in terms of area), Thua Thien Hue (which includes the Aluoi Valley) and Binh Dinh experienced the most number of spray missions (704, 606 and 558, respectively). Of the 47% Agent Orange used in the ten areas summarized, the above noted provinces received 6%, 9% and 6% of total usage. Dai *et al.* (1994a) state that the Aluoi Valley received 224 of the 606 spray missions for Thua Thien Hue province. Figure 1.1 shows a spray mission summary for southern Viet Nam. Figures 4.1 and 4.2 present the configuration and frequency of spray missions in the Aluoi Valley.

FIPI (1995) concluded that subsequent to herbicide application in the Aluoi Valley, forest cover, which extended over 80% of the total land area of the valley in 1965, was reduced to 50%. With forest cover being reduced significantly, marked alterations occurred in the once-forested ecosystem (i.e., invasion by less desirable floral species, soil and nutrient erosion, displacement and reduction of faunal populations).

People inhabiting the Aluoi Valley are surviving at a more or less subsistence level. Agriculture, aquaculture and raising of farm animals occurs throughout the valley. Generally, the people are poor and rely heavily on foodstuffs they produce. Collection of scrap metal (including bomb casings, shrapnel and other materials) is also a source of income (Plate 4.4). The valley experiences a minimal level of in/out migration of people. Appendix A1 provides a descriptive overview of the Aluoi Valley and its people (Plates 4.5 and 4.6).

Con Cuong, Chi Khe and Buu Chai were selected as reference sites. These areas are north of the former de-militarized zone (DMZ), and were not subject to herbicide applications. A slightly higher degree of prosperity was evident within the reference zones relative to peoples inhabiting the Aluoi Valley. However, the way of life and food sources of the two areas are similar.

FIELD METHODOLOGY AND SAMPLE COLLECTION

Background

Field components of this study were undertaken in January 1996 (Field Expedition 1) and November 1997 (Field Expedition 2). As noted in Section 2, the field sampling program was preceded by a reconnaissance of areas in Viet Nam affected by herbicide spraying. Given its history of herbicide applications, its strategic importance on the Ho Chi Minh Trail, lack of industrialization and relative isolation from heavily populated areas, the Aluoi Valley in Thua Thien Hue Province was the primary location selected for environmental sampling in both Field Expeditions.

Reference (control) areas were sampled in January 1996 in Con Cuong and Chi Khe, Nhge An Province, northern Viet Nam to provide comparative data from an area which was not sprayed with herbicides during the war (Plates 4.7 and 4.8). Additional samples were also collected from Quang Tri Province, near the DMZ, during Expedition 1. Results of the 1996 expedition indicated the presence of elevated dioxin levels in A So commune in the Aluoi Valley.

Expedition 2 focussed on sample collections in this area to confirm the presence of dioxin in key environmental media. Additional sampling was conducted in the Ma Da forest area in Dong Nai province in southern Viet Nam to provide comparative data on another intensely sprayed area.

A summary of sampling locations during the two expeditions is provided in Tables 4.1, 4.2, and Figures 4.4 and 4.6.

Sampling methods applied to this study were developed in previous dioxin/furan monitoring programs conducted by Hatfield Consultants Ltd. for the pulp and paper industry in British Columbia, and the British Columbia Ministry of Environment in Canada (a complete reference list is provided in Appendix A3). Field personnel consisted of a combination of Hatfield and Vietnamese biologists, a chemist, technicians, foresters, and medical doctors, all of who had experience in contaminant studies. A detailed environmental monitoring program was designed as a guide to field personnel (Hatfield Consultants Ltd. 1995).

During both field expeditions, the study team traveled to Ha Noi to meet with representatives of the 10-80 Committee and to arrange project logistics prior to commencing the field program. Meetings were also held with the Provincial Health Department in Hue, in addition to Peoples'

Committee representatives in each commune to explain the purpose of our program, to obtain permission and permits to collect samples, and to recruit local personnel to assist with logistics (Plate 4.9). In Aluoi District, the A Ngo Health Centre was designated as our key contact, and provided assistance in the form of transportation, lab space, freezer facilities, personnel (for blood sample collection), and liaison with the local Peoples' Committee representatives in each commune. In Ma Da, the sampling team used the office of the 10-80 Committee in Ho Chi Minh City as the main local contact for coordination of field activities.

Field supplies transported from Canada included all stainless steel sampling equipment (core samplers, pans, dissecting equipment, etc.), pre-cleaned glass jars with Teflon lids, heat-treated foil, electronic balances (+/- 0.1 g), a Garmin hand-held global positioning system (GPS), pre-numbered labels, data sheets and other items. Acetone and hexane were obtained in Viet Nam from the 10-80 Committee's dioxin laboratory in Ha Noi; chemicals used were imported from Japan, and were checked to ensure they were in their original packaging prior to use.

Quality Assurance and Quality Control (QA/QC)

Important components of the study included ensuring standard QA/QC procedures were followed during all sample collection activities, in addition to training of some Vietnamese scientists in ultra-trace contaminant sampling (Hatfield Consultants Ltd. 1995). The field team expended considerable time training Vietnamese counterparts in environmental sampling techniques, especially the importance of minimizing potential contamination of samples. Some important QA/QC considerations are described below:

- disposable latex gloves were used to handle all samples and specimens, and were dipped in hexane prior to sample collection and/or dissection; gloves were changed between samples and specimens;
- stainless steel dissection trays and tools (scalpels, forceps, calipers, etc.) were rinsed in ambient water, then acetone and hexane, before each use and between sample collections;
- sample jars were pre-cleaned by our Canadian dioxin analytical laboratory prior to shipment to Viet Nam;
- tools and gloved fingertips which touched the skin or external organs of sampled animals were not allowed to touch internal tissues; any tissue suspected of being contaminated in this manner was discarded;
- duplicate samples were collected at all sampling stations;
- all samples were placed in 250 mL heat-treated, wide-mouth glass jars and sealed with lids lined with heat-treated aluminum foil. Samples were appropriately labeled, stored in a cool/dark area, and transported to freezer facilities with two hours of collection (Plate 4.10);
- the location of each sampling station was recorded using a hand-held GPS, as well as still photography and video, to ensure repeatability in future sampling programs;

- detailed records were kept of the name of the owners of local farms, fields, fish ponds and animals sampled. Interviews with local residents provided essential data on the source of animals sampled (i.e., sex, age, origin);
- livestock (pigs, cows) were sampled immediately after being slaughtered by the local butchers (i.e., samples were not "purchased" from the market); and
- smoking was not permitted in the vicinity of sampling activities.

Sampling Methodologies

Soils

Composite soil samples were collected from a variety of soil types, including farmer's fields, forested areas and in the vicinity of former U.S. airbases (Tables 4.1, 4.2, and Figures 4.3, 4.4, 4.5 and 4.6). All soil samples were collected using a stainless steel core sampler, and consisted of ten "grabs" collected within a 100 m radius (Plate 4.11). Samples were divided into two categories, 0-10 cm depth (surface soils) and 10-30 cm (deeper soils), and were placed into separate stainless steel pans (Plate 4.12). Each sample was stirred into a homogenous mixture, and subsequently placed into separate glass jars. (Note: The only exception to the above was for sample collections in the Ma Da forest area, where soils were too compact to permit sampling below 10 cm; at these sites, only one composite soil sample [0-10 cm depth] was collected at each site).

Fish Pond, Bomb Crater Pond and River Sediments

Fish pond and bomb crater sediments were collected from a depth of approximately 60 cm below the water surface. The collector waded into the pond until the desired depth was reached, and scooped sediments directly into sampling jars, or by using a stainless steel pan (Plate 4.13). Two individual samples were collected at each site. (Note: composite samples were not collected in fish ponds and bomb craters to avoid extensive disturbance of bottom sediments).

River sediments from the A Sap River were collected from depositional zones along the river's edge (Plate 4.14). Samples were collected from ten different locations on the river bank using a stainless steel spoon, and subsequently placed into stainless steel pans. Each sample was stirred into a homogenous mixture, and placed into two separate, pre-labeled glass jars.

Fish Tissues

Fish sampling concentrated on locally-grown grass carp (*Ctenopharyngodon idella*) which are raised in fish ponds throughout the Aluoi Valley (Plate 4.15). In some cases, these ponds were formed by bomb craters, which have subsequently been stocked with fish to supplement local food supplies.

Attempts were also made to collect wild fish specimens from the A Sap and other local rivers by electrofishing. Sampling of wild fish was generally disappointing as few large specimens were captured at any of the sites sampled. According to local accounts, herbicide spraying during the war reduced fish populations considerably, from which they have never recovered. Harvesting pressure has probably also played a major role in keeping wild stock numbers low.

At each fishpond sampled, a maximum of four grass carp were collected using a hand seine (Plate 4.16). All target fish species were handled by personnel wearing latex gloves and placed in clean, well-labeled polyethylene bags. Fish were dissected within three hours of capture. Fork length (mm), whole weight (g), and sex (visual inspection of gonads) were recorded for each specimen in the composite sample. Muscle tissues (skin removed) were collected from the left side of each fish, above the lateral line, and between the dorsal and caudal fins (Plate 4.17). Liver tissue samples were also collected (entire livers were removed from each specimen), as was fish fat (collected from the viscera), and occasionally fish roe (eggs). Samples were placed in individual jars for each type of fish tissue, and frozen immediately after dissections were complete.

Vegetation

Manioc (a staple in the local diet) was sampled at several locations in the Aluoi Valley and in control areas (Plate 4.18). The manioc tubers were pulled from the ground and excess dirt removed by hand. The outer skin was removed, and the sample washed in local water before placing it in a jar.

Sweet potatoes were also collected. Samples were dug up using a spade, and the unpeeled tubers were washed in local well water before being placed in a sample jar.

Manioc and sweet potato leaves were also collected, as these items are consumed by local residents. Leaves were placed in individual glass jars, sealed, and frozen.

Other plant materials collected included:

- Rau Ua – a small leafy vegetable, consisting of one leaf on a single stem. Soldiers during the war used this plant as a water source. People from Hue and HCMC presently use it to make a medicinal drink. It is also cooked in dishes, or served raw with other vegetables; and

- Rau Tau Bay – people eat the young shoots for nourishment; this plant was a staple of Vietnamese troops during the war, as it was apparently resistant to herbicide spraying; it is presently eaten by local Taoi villagers (boiled).

Livestock and Fowl

Two markets in the Aluoi Valley were sampled for livestock (pork and beef): #91 market (Ango village) and Bo Dot market (Hong Thuong). The study team visited these markets on several occasions, and made inquiries regarding schedules for slaughtering of livestock. Pigs and cows were sampled immediately after slaughtering (Plate 4.19) to ensure samples were not contaminated by other food items in the markets. Liver tissues were removed from the lower left lobe; fat was collected from around the chest area, and muscle tissues from the shoulder area. Approximately 50 g of each tissue type was collected, placed in individual glass jars, and frozen subsequent to collection.

Chicken and duck were purchased from local residents in each village. Muscle (breast meat), liver and fat tissues were extracted, weighed (+/- 0.1 g), placed in individual glass jars, and frozen (Plates 4.20 and 4.21).

Human Blood

Blood sampling was conducted in A So village by staff of the Aluoi Health Centre. Pooled blood samples (N=50 per sample) were collected from four groups of villagers:

- Males 12-25 years of age (representing "post war" residents);
- Females 12-25 years of age (representing "post war" residents);
- Males >25 years of age (representing residents born before or during the war); and
- Females >25 years of age (representing residents born before or during the war).

Each volunteer donor was interviewed by the Health Centre staff to determine name, age and personal medical history. Approximately 1 ml of blood was removed from each patient using a syringe (Plate 4.22), and was subsequently placed in glass jars (one sample per group; total of four samples). Whole blood samples were kept cool on ice packs during the sampling procedure (Plate 4.23), and frozen within one hour of collection.

All samples were frozen subsequent to collection and kept frozen in freezers in Aluoi Valley, Hue, Ha Noi and/or Ho Chi Minh City depending on the port of departure from Viet Nam. Appropriate arrangements were made with carriers to ensure samples remained frozen during transport to Canada.

ANALYTICAL METHODS

General

Samples arriving from Viet Nam were forwarded to AXYS Analytical Services Ltd. for dioxin analyses.

Axys Analytical was one of 26 laboratories from around the world that participated in a World Health Organization (W.H.O.) intercalibration study of dioxins/furans and PCBs in human blood plasma and breast milk. Axys' results were judged to be among the best of all labs participating. The W.H.O. will be releasing a technical report describing the study and results achieved. Based on discussions at a recent post-study meeting held in Stockholm, Axys expects to be recommended as one of the few W.H.O. - approved labs for these analyses (*pers. comm.* Dr. C. Hamilton, Axys Analytical).

During the several weeks the Hatfield team spent in the Aluoi Valley during the two collecting expeditions, it was noted that there did appear to be very limited use of pesticides in agricultural regions. Discussions with locals confirmed this; it was also stated by residents that the cost of pesticides was such that it precluded frequent and extensive use throughout the valley.

Nevertheless, it was decided to select a small number of samples to test for specific pesticides and herbicides since it is sometimes speculated that residues of these chemicals can be confounding factors in dioxin studies. Although it was not suspected to be a significant compound in the area, the team also elected to test for PCBs in certain samples. Tables 4.5, 4.6 and 4.7 list the pesticides, herbicides and PCBs targeted for analyses.

The following is a summary of laboratory methods for the analyses performed during this investigation. For more details on methods involving extraction, chromatographic cleanup, high resolution GC/MS analysis and quantitation procedures, refer to Appendix A2.

Polychlorinated Dioxins and Furans in Soil and Tissue Samples

All samples were spiked with ^{13}C-labelled surrogate standards (tetrachlorodioxin, tetrachlorofuran, pentachlorodioxin, pentachlorofuran, hexachlorodioxin, hexachlorofuran, heptachlorodioxin, heptachlorofuran, and octachlorodioxin) prior to analysis. Soil samples were soxhlet extracted. Tissue samples were ground with sodium sulphate, loaded into a glass chromatographic column and eluted with solvent. All extracts were subject to a series of chromatographic cleanup steps prior to analysis for polychlorinated dibenzodioxins and dibenzofurans by high resolution gas chromatography with high resolution mass spectrometric detection (HRGC/HRMS).

Polychlorinated Dioxins and Furans in Whole Human Blood

All samples were spiked with ^{13}C-labelled surrogate standards (tetrachlorodioxin, tetrachlorofuran, pentachlorodioxin, pentachlorofuran, hexachlorodioxin, hexachlorofuran, heptachlorodioxin, heptachlorofuran, and octachlorodioxin) prior to analysis. Blood samples were liquid/liquid extracted by shaking with solvent and ammonium sulphate solution. All extracts were subject to a series of chromatographic cleanup steps prior to analysis for polychlorinated dibenzodioxins and dibenzofurans by high resolution gas chromatography with high resolution mass spectrometric detection (HRGC/HRMS).

PCBs and Chlorinated Pesticides in Soil and Tissue Samples

All samples were spiked with a suite of ^{13}C-labelled surrogate standards (hexachlorobenzene, gamma-BHC, p,p'-DDE, p,p'-DDT, Mirex, PCB 101, PCB 180, and PCB 209) and perdeuterated alpha-endosulphan. Soil samples were solvent extracted. Tissue samples were extracted by grinding with sodium sulphate followed by elution through a glass column with solvent. The final extracts were separated into two fractions on a Florisil column. One fraction was analyzed by high resolution gas chromatography with detection by either quadrupole or high resolution mass spectrometry for PCBs (as Aroclors) and non-polar and moderately polar chlorinated pesticides. A second fraction was analyzed for the most polar chlorinated pesticides by gas chromatography with election capture detection (GC/ECD).

Phenoxy Acid Herbicides in Soil and Sediment

Protocols for these analyses were adapted from U.S. EPA Method 8151A (Publ. #SW-846 3rd ed., Washington, DC 20460). The procedure involves a liquid-solid extraction of the soil/sediment sample with a mixture of acidified acetone and diethyl ether. The acetone/diethyl ether extracts were combined into a separatory funnel; reagent water was added. Additional diethyl ether was added and the herbicides subsequently extracted by liquid-liquid extraction. The diethyl ether extract was concentrated, methylated with diazomethane and analysed by capillary column gas chromatography with mass spectrometric detection.

RESULTS

Figures 4.3, 4.4, 4.5 and 4.6 summarize the locations and sample type collected during the 1996 and 1997 sampling expeditions. The sampling of areas in the Ma Da forest in 1997 was linked to a laboratory technology transfer program also undertaken by Hatfield Consultants Ltd.

Samples analyzed for dioxin/furans in both 1996 and 1997 are highlighted in the above-noted figures. Due to budgetary constraints, only select samples were analyzed from the entire complement of environmental samples collected. From the 1996 series of samples (Table 4.1), a total of 28 dioxin analyses were run at Axys Analytical laboratories in Canada. In order to obtain some information on the prevalence of pesticides, herbicides and PCB residues in the Aluoi Valley, nine samples were selected for pesticide and herbicide residue tests; six of these samples were analyzed further for PCB residues. A total of 22 samples were analyzed for dioxins from the 1997 sample series (Table 4.2). Thirteen and nine tests, respectively, were performed at Axys and the Environmental Technology Centre (ETC) laboratory in Canada operated by Environment Canada. Two additional pesticide/PCB analyses were run on Aluoi Valley soils in 1997.

Analytical summaries for the 1996 and 1997 dioxin data are presented in Tables 4.3 and 4.4. These summaries list separately the 2,3,7,8-T4CDD and 2,3,7,8-T4CDF values; other dioxin/furan congeners are presented as a “Total”.

Total TEQs are calculated for each sample with a percentage of the total TEQ that is represented by the 2,3,7,8-T4CDD congener. Data in Tables 4.3 and 4.4 and Figures 4.7, 4.8, 4.9, 4.10, 4.11 and 4.12 are summaries of complete data spreadsheets for each of 1996 and 1997 (Appendix A2.1), which in turn have been generated from individual analytical sheets provided by the respective analytical laboratory (Appendix A2.2, A2.3 and A2.4).

Dioxins – 1996 Expedition

The 1996 sampling program was undertaken in an attempt to determine if there existed significant variations in contaminant concentrations throughout the Aluoi Valley.

Table 4.3 and Figures 4.7 and 4.8 show that samples collected in the A So region of the Aluoi Valley exhibited the highest TEQ levels. The 2,3,7,8–T4CDD congener (characteristic of Agent Orange) in samples from A So formed the highest proportion of the total TEQ calculation (range 66.7% - 97.7%; mean 89.1%; coefficient of variation [CV] 11.9%). Other regions in Aluoi exhibited markedly lower TEQs and similarly a lower proportion of 2,3,7,8-T4CDD congener influence on the total TEQ value (range 0.0% - 84.2%; mean 51.4%; CV 62.2%).

The highest TEQ (112.6 pg/g; Figure 4.7) recorded during the 1996 program was in former airbase soils (0 – 10 cm depth fraction). The 10 – 30 cm fraction yielded a TEQ of 33.3 pg/g.

The highest biological tissue dioxin value was recorded in carp fat (53.7 pg/g TEQ; Figure 4.8), also from A So. This carp fat sample was collected from the same fishpond which contained sediments with a TEQ of 7.8 pg/g. Carp fat is considered by local people to be a preferred portion of a local fish meal (personal experience of Hatfield field crew members). The high lipid content of fat tissue would serve as a major reservoir for dioxin molecules.

Fishpond sediment at A Ngo (Table 4.3 and Figure 4.7) exhibited a slightly reduced TEQ (6.8 pg/g) relative to A So (7.8 pg/g). Farmer's field soil in Aluoi exhibited 2,3,7,8-T4CDD levels of 1.7, 0.7 and 4.3 pg/g (Figure 4.7).

Samples collected from Dong Ha, and control areas at Chi Khe and Con Cuong did not contain the 2,3,7,8-T4CDD congener and exhibited very low TEQ values (range 0.6 - 1.6 pg/g; Table 4.3).

The total O8TCDD(octa-) fraction yielded the highest concentrations of all dioxin congeners (Table 4.3). Bomb crater soil and fishpond sediment from A Ngo, farmer's field soil from Hong Van, and airbase soil and fishpond sediment from A So exhibited the highest O8TCDD totals (Table 4.3). Congener profiles for each analysis on 1996 material are presented in Figures A2.1.1, A2.1.2, A2.1.3 and A2.1.4 (Appendix A2).

The 1,700 pg/g O8CDD recorded in farmer's field soil (Hong Van) was the highest octa congener determined in 1996 (and 1997). Perhaps burning of crop remains contributed to farmer's field soil values for O8CDD; however, elevations of this congener were not consistent (e.g., Chi Khe), if field burning was a common denominator. No information on crop handling variations was obtained.

Bomb crater soil values (A Ngo) were perhaps residual compounds created by the explosive forces that formed the crater. Fishpond sediment O8CDD in A Ngo (880 pg/g) could be related to run-off catchment. It could not be ruled out that this fishpond was once a bomb crater, as this practice does occur in the valley.

Dioxins - 1997 Expedition

From an overview of 1997 data, as in 1996, it is evident that surficial soils collected near the former A So airbase exhibited the highest TEQs consisting primarily of the 2,3,7,8-T4CDD congener (Table 4.4, Figure 4.10) – indicative of the orange herbicide signature (Schecter *et al.* 1990; *pers. comm.* Dr. C. Hamilton, Axys Analytical Services Ltd.). The high percentage of 2,3,7,8-T4CDD in virtually all samples collected throughout Aluoi confirms orange herbicide as the principle factor in determining TEQ values.

From A So (Table 4.4) the mean percent 2,3,7,8 – T4CDD contribution to total TEQ was 89.9% (range 76.9% - 99.6%; CV 7.2%). In southern Viet Nam, Rang Rang region also exhibited high 2,3,7,8-T4CDD contribution to total TEQ values (mean 89.8%, range 76.8% - 98.4%, CV 7.5%) (Table 4.4, Figure 4.11). The Ma Da region within southern Viet Nam was also heavily sprayed with Agent Orange. These data (A So and Rang Rang) confirm that Agent Orange was the principle factor affecting TEQ values. The TEQ of former airbase/airstrip soils consisted primarily of 2,3,7,8-T4CDD (Table 4.4 and Figures 4.10 and 4.11). Surface soils (0 – 10 cm) north of the Ma Da River exhibited a 2,3,7,8-T4CDD level of 19.1 pg/g, with a TEQ of 20.3 pg/g (Table 4.4 and Figure 4.11).

During the collection of fishpond sediment in 1997, a fish sample was collected from each of the four ponds. Figure 4.9 depicts total TEQ and 2,3,7,8-T4CDD percentages in each of the four fishpond sediments with corresponding carp fat analyses.

With the exception of fishpond #4, as you progress from fishpond #1 to fishpond #4 an increasing 2,3,7,8-T4CDD in carp fat corresponded to an increasing value for this parameter in sediments in each pond. Pond #4 appeared to be an anomaly where a decline relative to the pond #3 sediment figure was recorded; however, the carp fat level from pond #4 continued to increase relative to pond #3. These data suggest there may not be an equitable distribution of contaminants in sediments within a given fishpond. Pockets of contamination may exist; our team probably sampled a less contaminated pocket of bottom sediments. Carp being able to forage throughout a pond would ingest materials from an entire pond area, which would result in a more representative contaminant concentration for that particular pond.

Terrestrial animal fat was also tested (duck fat, Table 4.4, Figure 4.9). A TEQ of 7.0 pg/g was determined with an 88% contribution of 2,3,7,8-T4CDD to the TEQ calculation. Ducks will forage in ponds for food.

Manioc field and ploughed field soils exhibited TEQ values of 7.0 pg/g and 4.5 pg/g, respectively Table 4.4 and Figure 4.10).

Sediment from a fishpond near the Ba Hao reservoir and from the Ba Hao reservoir itself had TEQs of 7.9 pg/g and 2.6 pg/g, respectively (Table 4.4 and Figure 4.11).

Males greater than 25 years of age exhibited the highest TEQ value and the highest 2,3,7,8-T4CDD value (37.2 pg/g and 31 pg/g, respectively; Table 4.4, Figure 4.12); males born post-war followed (25.5 pg/g and 21 pg/g, respectively).

Figure 4.12 displays dioxin levels (TEQ and 2,3,7,8-T4CDD concentrations) in human blood collected from inhabitants of the A So area of the Aluoi Valley. Four categories of individuals were established: males greater that 25 years of age, females greater than 25 years of age, males 12 – 25 years of age, females 12 – 25 years of age; each category consisted of a pooled blood sample collected from 50 individuals (1 ml per individual).

The following table presents a summary of the age data for those people participating in the 1997 blood program (refer to Appendix Table A2.1.3 for more complete statistics on all participants).

Summary statistics of participants in 1997 blood program, A So (Aluoi Valley).

Sex/Age Category (years of age)*	Mean Age	+/- 1 Standard Deviation	Coefficient of Variation (%)
Males (>25)	59	15	25.4
Females (>25)	51	13	25.5
Males (12-25)	19	4	21.1
Females (12-25)	21	4	19.0

*Note: N=50 in each category.

Pesticides/Herbicides/PCBs

Tables 4.5, 4.6 and 4.7 summarize analytical data for 23 pesticide residues, nine herbicide residues and PCBs (Aroclor 1242, 1245 and 1260).

The highest level of pesticide residue was detected within the reference areas. The most prevalent residue was of the DDD, DDE and DDT groups (Table 4.5). The highest concentration was p,p'-DDT, which was detected at levels of 11,000 ng/g and 15,000 ng/g in the 0 – 10 cm and 10 – 30 cm fractions of a farmer's field soil sample, respectively (o,p'-DDT, was 1,200 ng/g and 1,100 ng/g for the same soil depths, respectively). Other DDD and DDE groups were detected at a range of 60 ng/g to 2,500 ng/g.

Soils from A So in 1997 exhibited low concentrations of certain pesticides (Table 4.5); these were DDD, DDE and DDTs (1.1, 2.0 and 0.41/1.0 ng/g, respectively). PCBs were not detected in the 1997 A So soil samples.

Hexachlorobenzene was the only other pesticide residue detected in reference soil at low levels.

Pig liver tissue from the reference area contained low levels of p,p'-DDE and p,p'-DDD (0.76 ng/g and 0.4 ng/g, respectively). Pig liver in the exposed area in Aluoi yielded approximately twice as much p,p'-DDE and p,p'-DDD, at values of 1.5 ng/g and 0.92 ng/g, respectively.

Carp fat from A So (Aluoi Valley) contained a greater number of individual pesticide residues than did pig liver (Table 4.5).

Soils at former airbases yielded low levels of a variety of residues (Table 4.5).

Nine different herbicide residues were tested for in six soil samples (Table 4.6). No detectable levels were found.

The only samples that exhibited some level of PCBs were those collected from former airbases (Table 4.7). The operation of these bases probably involved the use of materials containing PCB. PCBs were not detected in any other sample (soil or biological tissue).

DISCUSSION

General

The purpose of our investigation was to undertake a systematic preliminary assessment of residual dioxin contamination in the environment of southern Viet Nam related to historical herbicide spraying. A major constraint was high analytical cost which restricted the analysis to 28 samples in 1996 and 22 samples in 1997.

Our approach involved the study of an isolated area (Aluoi Valley) where the potential for confounding variables (i.e., other sources of environmental contamination) would be minimized. We elected to focus on the food chain in the Aluoi Valley. The principle target was to assess the possible movement of dioxin contamination up the food chain to humans in a defined area.

We restricted our 1996 sampling to the Aluoi Valley, with relatively dispersed sampling throughout the valley (Figure 4.4). Data from this program (Table 4.3) suggested that samples from the commune of A So exhibited the highest levels of 2,3,7,8-T4CDD and total TEQ. As a consequence, the 1997 expedition focussed on the A So commune (Figure 4.6). We also included samples from another heavily sprayed area (Ma Da) to obtain some measure of the uniqueness of the A So area. Table 4.4 summarizes dioxin levels that were generated from materials collected in the A So (and Ma Da) sampling regions.

The collection of specific environmental media and human blood samples for dioxin analyses followed a rigorous assessment of the potential geographic areas available for the study, and the quantitative requirements necessary to draw reliable conclusions regarding contamination status in the valley. The number of samples ultimately selected for dioxin analyses (total of 50) represent only a small proportion of the actual samples collected in 1996 and 1997. The team's experience over the past decade in Canada, and our experience in the monitoring of dioxins in pulp and paper mill wastewater discharges, provided insights into an acceptable experimental design for the Aluoi Valley.

The number of samples selected for dioxin analyses are adequate to provide data on the general state of dioxin contamination in the Aluoi Valley, and more specifically the A So commune. These data form a dependable base for the planning of future programs. In British Columbia, Canada, similar programs with comparable sample sizes have resulted in regulatory agencies taking action to protect human health and define the status of contaminated sites.

Dioxins

Samples tested for dioxins in 1996 consisted of soil, fishpond sediments, river sediments, vegetable matter, terrestrial animal tissues and fish tissues. In 1997, the categories of materials tested included soils, fishpond sediment, fish and terrestrial animal tissues, and human blood.

The following discusses analytical results according to environmental media collected and analyzed.

Soils

The highest soil concentrations of dioxins (2,3,7,8-T4CDD) in the Aluoi Valley, apart from the former airbase locations, were detected in farmer's field soil (10-30 cm depth, Figure 4.7) in 1996 (4.4 pg/g) and manioc field soil (0-10 cm depth, Figure 4.10) in 1997 (6.61 pg/g). A level of 4.2 pg/g was detected in 1997 from a ploughed field (Figure 4.10). In these three samples from Aluoi Valley soils, 86%, 94% and 93% of the total TEQ consisted of the 2,3,7,8-T4CDD congener. 2,3,7,8-T4CDD was not detected in reference areas.

Other soils (non airbase) in 1996 exhibited 2,3,7,8-T4CDD from non-detect levels to 1.7 pg/g with comparably low TEQ values.

Soils from the Ma Da forest area yielded a 19.1 pg/g of 2,3,7,8-T4CDD and a total TEQ of 20.3 pg/g (94% of the TEQ being 2,3,7,8-T4CDD; Figure 4.11); the high percentage is indicative of Agent Orange.

Matsuda *et al.* (1994) reported soil levels of 2,3,7,8-T4CDD from various regions of southern Viet Nam. A total of 106 soil samples were collected over four sampling periods between 1989 and 1991. When detected, 2,3,7,8-T4CDD levels ranged from 1.2 pg/g to 59 pg/g (detection level 1.0 pg/g). Only 21 of the 106 samples yielded detectable levels of 2,3,7,8-T4CDD. They concluded that leaching and run-off contributed to the gradual removal of the compound from surface soils. They also indicated that dioxin could not be detected in soils at depths greater than 10 cm. However, our study indicates that the 2,3,7,8-T4CDD congener can be present in soil depths greater than 10 cm (Figure 4.7).

Quynh *et al.* (1994) also reported 2,3,7,8-T4CDD in Vietnamese soils. A 1985 sample from the Aluoi Valley yielded 1.0 pg/g at a depth of 20 cm. In 1990 they reported a value of 62.7 pg/g at a depth of 10 cm near Bach Ma which is situated between Hue and Da Nang; the 10-20 cm depth fraction exhibited a 2,3,7,8-T4CDD value of 17.3 pg/g.

Our data also support the contention that those areas which had received Agent Orange application now yield relatively low soil levels of dioxin. The natural influences of leaching, run-off and tropical rains would tend to disperse the compound; however, in all soil samples collected, some 2,3,7,8-T4CDD was detected.

The most notable concentrations of 2,3,7,8-T4CDD were detected at the former U.S. airbase at A So. These values indicate significant contamination in those areas, both in 1996 and 1997 (Figure 4.7 and 4.10) and particularly at the 0-10 cm level (100 pg/g and 897.85 pg/g, respectively).

Given that the soil samples analyzed for dioxin consisted of a composite of ten soil cores, there is high potential for some individual core values to exceed the composite value (i.e., a higher level of dioxin contamination than reported in the composite core sample); similarly individual cores may have lower contamination levels.

It would appear that airbases had potential for significant soil contamination during the conflict by virtue of their role as a depository and dispensation point for Agent Orange. We are aware of Japanese data (1989) on soils from the Bien Hoa airbase which exceeded the $1x10^6$ pg/g 2,3,7,8-T4CDD (*pers. comm.* Dr. Hoang Dinh Cau, Chairman of the 10-80 Committee). The base was re-sampled again in 1994; the result was similar, in the order of $8x10^5$ pg/g 2,3,7,8-T4CDD (*pers. comm.* Dr. Hoang Dinh Cau). Samples were analyzed in Japan.

These values are not surprising given that the Bien Hoa airbase experienced several spills/leaks of Agent Orange. On March 1, 1970, a leak of approximately 7,500 U.S. gallons of Agent Orange was detected (*pers comm.* U.S. Department of the Army, Springfield, Virginia, January 8, 1997: declassified documents). Other leaks and spills in the order of 100-500 U.S. gallons were also reported for the Bien Hoa base.

Schecter *et al.* (1986) reported that the anti-fungal agent pentachlorophenol (PCP) was commonly used by American forces in southern Viet Nam. It would seem logical that airbases with wood fabrications would be a major site of PCP use. Schecter (1986) also indicates that PCP typically contained octa- through pentachlorinated dioxins and furans in decreasing concentrations. In 1997 (Table 4.4), the airbase and airstrip total 08CDD (octa-) was the highest recorded of all the samples tested, with H7CDD (hepta-), H6CDD (hexa-) and P5CDD (penta-) values decreasing as noted above.

Soil data can be placed in the context of contaminated site legislation in British Columbia, Canada. A contaminated site means a site at which "the concentration of any substance in the soil at the site is greater than or equal to the applicable generic numerical soil standard".

For agricultural and residential soils, 350 pg/g (total TEQ) is the standard for protection of human health (Waste Management Act 1996). In addition, an environment protection standard has been established for dioxins addressing toxicity to soil invertebrates and plants in agricultural areas; this standard is 10 pg/g TEQ (Waste Management Act 1996).

Given these criteria, airbase soils in 1996 and 1997 (Tables 4.3 and 4.4) and soil from north of Ma Da would be classified as contaminated by British Columbia regulations regarding soil concentrations for agricultural and residential use.

In the Aluoi Valley, fishponds are excavated out of the local terrain. It is logical to conclude that if soils are contaminated, fishpond sediments would in turn become contaminated. Fishpond sediment dioxin levels are discussed in the following sections. Such contamination was detected, with resulting bioaccumulation/biomagnification of dioxins occurring in fish. The higher the contaminant level in soil, the greater the probability that sediments in ponds excavated from these soils would similarly be contaminated, with the probable passage of dioxin into cultured fish inhabiting these ponds.

Soil information from the present study indicates that the highest levels of contamination persist near the former U.S. airbase at A So. The Dong Ha base (Figure 4.7) did not exhibit comparable soil concentrations to those determined at A So. Given the A So base was a Special Forces installation, perimeter spraying, etc. was perhaps more prevalent than at Dong Ha.

Our data and information from Bien Hoa suggest that former U.S. airbases, whether they have been totally abandoned or are presently being used by the Vietnamese military, have high potential for significant soil contamination. Other former U.S. or allied army, navy and marine bases could also have contaminated soils since Agent Orange ground and helicopter spraying occurred around virtually all installations during the war. Regions in close proximity to these bases may also exhibit elevated contaminant levels due to the configuration of drainage patterns in the area.

River Sediments

It was not expected that river sediments in the Aluoi Valley would yield excessively high concentrations of dioxins. With tropical rains and the scouring effect on bottom and perimeter sediments, erosion and subsequent transport was undoubtedly a major factor in contaminant removal from the immediate vicinity of the Aluoi Valley. Only one bottom sediment sample was collected from the A Sap River in a depositional zone of the river. A total TEQ of 1.2 pg/g with a 2,3,7,8-T4CDD level of 0.8 pg/g was detected (Table 4.3). These samples were sandy, and appeared to have a low silt/clay/organic fraction; if this fraction were higher, a higher dioxin level might have resulted.

Schecter *et al.* (1989b) reported high 08CDD in sediments from the Saigon River and Dong Nai River, with reduced levels in the Red River (northern Viet Nam). The analytical protocol applied to their samples (i.e., ionization mode) apparently provided a poor response for 2,3,7,8-T4CDD; however, other tetra-dioxins would have been detectable if present. Schecter *et al.* (1989b) were unable to detect any T4CDDs in their study (detection limit 0.1 pg/g).

Quynh *et al.* (1994) reported non-detectable levels of dioxin in silt samples collected from the Dong Nai River and the Hong River in 1985. However, a level of 231 pg/g of 2,3,7,8-T4CDD was detected in sediments from a canal off the Saigon River in the centre of Ho Chi Minh City. Given that no spraying of herbicides occurred in Ho Chi Minh City, they concluded that transport and deposition of particulates from upstream sprayed areas was responsible for levels observed within Ho Chi Minh City proper. Deposition of sediment layers over time could render these contaminants relatively inaccessible. Core sampling could clarify present contaminant levels at greater depths by profiling of contaminants within the sediment column.

Fishpond Sediments

Fishponds in the Aluoi Valley are excavated out of the local landscape and ultimately used to provide an additional source of protein to local inhabitants. Old bomb craters are sometimes used. Fish are cultured to a harvestable age in these ponds and distributed throughout the valley through local markets.

The pond at A So exhibited the highest 2,3,7,8-T4CDD value (6.9 pg/g) of three fishponds sampled in 1996 (Figure 4.7). This pond supported a carp with high 2,3,7,8-T4CDD in fat tissues (see following section). It was these tissue data in 1996 that precipitated a further examination of fishponds and resident fish tissues during the 1997 program.

In 1997, four ponds were sampled in the A So commune. 2,3,7,8-T4CDD sediment levels ranged from 1.8 to 8.5 pg/g. One additional pond was sampled near Ba Hao in southern Viet Nam (7.8 pg/g 2,3 7,8 –T4CDD). 2,3,7,8-T4CDD comprised a high percentage of the total TEQ for each of the ponds sampled (range 78% to 92%); these percentages being indicative of Agent Orange involvement.

There is probably a resuspension of particulates in fishponds due to human and fish activity during periodic captures of fish, etc. This would enable ingestion of contaminated particulates during feeding which might have originally settled at greater depths in bottom sediment profiles. This could set in motion the process of bioaccumulation and biomagnification in resident fish species.

Fish Tissues

Carp fat from A So (Figures 4.8 and 4.9) exhibited elevated concentrations of 2,3,7,8-T4CDD. Total TEQ values in the 1997 collection ponds were 8.7 ppt, 16.7 ppt, 22.4 ppt and 35.4 ppt; the 2,3,7,8-T4CDD congener made up 91%, 96%, 94% and 96%, respectively, of the above noted total TEQ value for that particular sample. The single 1996 sample exhibited a TEQ of 53.7 ppt with a 2,3,7,8-T4CDD contribution to the total TEQ of 95%. These high relative percentages of 2,3,7,8-T4CDD confirm significant involvement of Agent Orange in tissue residue levels.

Quynh *et al.* (1994) summarize fish fat concentrations of 2,3,7,8-T4CDD dating back to 1970; values ranged from 18 ppt to 540 ppt. All samples were collected from southern regions of Viet Nam.

It should be noted that analytical methods for dioxins have made significant progress since the 1970's. The reliability of early dioxin data is somewhat questionable, as it was not until the mid-1980's that reliable standards and ^{13}C-labeled materials became available for dioxin analyses. In addition, it has been only since the early 1990's that high resolution mass spectrometers became common practice for dioxin analyses (*pers. comm.* Dr. C. Hamilton, Axys Analytical, British Columbia, Canada).

Health Canada has established criteria for dioxin levels in tissues consumed by humans. High-lipid fish and shellfish tissues (e.g., liver, hepatopancreas and fat) tend to accumulate higher concentrations of dioxins due to their affinity for the lipid molecule. In Canada, the 53.7 ppt (Figure 4.7) and 35.4 ppt (Figure 4.9) would have resulted in action being taken by Health Canada regarding the issuance of consumption advisories. These values exceed the maximum level of 30 ppt total TEQ which would trigger a consumption advisory response based on a tolerable daily intake of 10 pg/kg body weight per day, as recommended by the World Health Organization.

In Maine, U.S.A., Frakes (in Mower 1996) states that edible portions of fish (he defines this as fillets) should not exceed 0.15 ppt 2,3,7,8-T4CDD for a 1 in 1,000,000 upper limit cancer risk, or 1.5 ppt 2,3,7,8-T4CDD for 1 in 100,000 cancer risk. For the protection against adverse reproductive effects, the Department of Human Services Bureau of Health in Maine recommend tissues, in general, should not exceed 0.37 ppt 2,3,7,8-T4CDD, a very low level of contamination, and lower than the majority of biological tissues analyzed from the Aluoi Valley.

Hatfield Consultants personnel visited Sweden, Finland and West Germany in 1988 as a member of a Canadian contingent representing certain pulp and paper companies in British Columbia. One of the objectives was to obtain information on organochlorine compounds (of which dioxin is a member) and their impacts on the environment. The "organochlorine" issue and chlorine bleaching was rapidly causing concerns in Canada. It was noted in Sweden at that time that a number of consumption advisories were in place regarding organochlorine-contaminated fish from the Baltic Sea (Dwernychuk 1989):

- pregnant women were advised to limit their intake of fish;
- nursing mothers were advised to breast feed for a period not exceeding four months; and
- during breast feeding, mothers were advised to avoid weight loss which could result in the release of contaminants from fatty tissues into breast milk.

There was serious recognition of the potential risks that existed in the consumption of dioxin-contaminated foods.

Fish are a major source of protein in the Aluoi Valley (Appendix A1). Given that local inhabitants of Aluoi view fish fat as a preferred portion of a fish meal, the dioxin contamination levels of these tissues are a concern in terms of transfer to humans throughout the valley.

In Canada, and more specifically British Columbia, dioxins in the food chain near pulp and paper mills have resulted in significant area closures for fish/shellfish. Rivers in BC were also under consumption advisories as a result of dioxin contamination. Of primary concern was the exposure of the general public to dioxins and furans through consumption of fish and shellfish tissues (Gilman *et al.* 1991), and the long term effects of these compounds on the receiving environment (McLeay and Associates 1987; CEPA 1990).

Manioc/Pig/Duck Tissues

The two manioc samples tested in 1996 did not contain any detectable levels of 2,3,7,8-T4CDD. Only a small amount of 08CDD was detected in one sample (1.1 ppt, Table 4.3). A low probability exists that vegetable matter would pose a significant dioxin problem (see Appendix A3).

Pig liver exhibited no 2,3,7,8-T4CDD in the Aluoi Valley or Con Cuong (reference area).

Duck liver from A So had 1.4 ppt 2,3,7,8-T4CDD (total TEQ 1.6 ppt, Table 4.3) while the reference area resulted in non-detectable levels in duck liver. In 1997, at A So, a duck fat sample had a 2,3,7,8-T4CDD level of 6.1 ppt (Total TEQ 7.0 ppt, Table 4.4).

Cau *et al.* (1994b) summarized a series of analyses on a variety of Vietnamese food samples. They concluded from their 1984-1989 sampling program of a variety of food materials from northern and southern Viet Nam, that their data suggested that "dioxin levels have normalized since the spraying of Agent Orange".

Many of the tissues analyzed in our study from the Aluoi Valley greatly exceed values presented in Cau *et al.* (1994b; compare their Table 1 with our Figures 4.8 and 4.9).

The above noted comparison indicates that in the Aluoi Valley (and probably elsewhere throughout Viet Nam) enclaves of Vietnamese people exist that may be subjected to higher than normal concentrations of dioxins as a result of dioxin "hot spots". A narrow range of food stuffs in their diet (as in the case of Aluoi Valley residents) would tend to exacerbate the situation. Circumstances in the Aluoi Valley are not believed to be unique in Viet Nam.

Westing (1984a) calculated a "rough approximation" of dioxin (2,3,7,8-T4CDD) applied per unit area (mg/ha) in southern Viet Nam during the war. On the basis of volumetric expenditures of herbicide in each Corps Tactical Zone (CTZ; CTZs I, II, III and IV; Figure 1.1), Westing (1984a) indicates that for these regions the dioxin amounts were 10.3 mg/ha, 4.6 mg/ha, 29.8 mg/ha and 4.0 mg/ha, respectively (assuming a uniform distribution of dioxin over each CTZ).

The Aluoi Valley (in CTZ I) experienced heavy Agent Orange activity. Given that the calculated amount of dioxin in CTZ III was ~2.9 times higher than the amount calculated for CTZ I, and CTZ III covered a greater area than CTZ I by a factor of only 1.1 (CTZ I = 2812×10^3 ha, CTZ III = 3021×10^3 ha; Westing 1984a)*, there is a high probability that other "hot spots" exist in Viet Nam within other CTZs (including CTZ I) where intensive activities involving Agent Orange occurred (e.g., airbases, fire support bases, heavily sprayed combat areas, etc.).

Dioxin data collected from the Ma Da region of southern Viet Nam (Table 4.4; Figures 1.1 and 4.11), in conjunction with the Japanese data on soils from the vicinity of the Bien Hoa airbase, tend to provide further credence that enclaves of Vietnamese are potentially inhabiting "hot spots" throughout southern Viet Nam and consuming contaminated foods.

Human Blood

Table 4.4, Figure 4.12 and various tables and figures in Appendix A2.1 summarize the data and congener profiles for the pooled blood samples analyzed.

Dai *et al.* (1994a, 1995) and Schecter (1992a, 1994b) summarize blood data (ppt, lipid) in Viet Nam covering the approximate period 1987 to 1992. These data are presented in Figure 4.13. Data from the 1997 Hatfield/10-80 Committee program in the Aluoi Valley are also presented in Figure 4.13. Of all the 2,3,7,8-T4CDD data points presented throughout Viet Nam, Song Be (32 ppt) and Can Tho (33 ppt) exceeded the 31 ppt from A So (Aluoi Valley) in 1997 (males, >25 years of age). Males <25 years of age (21 ppt) from A So (1997) exceeded all but those values noted above, and the 28 ppt from Dong Nai.

Female blood samples from A So both > and <25 years of age exceeded, or were near equal to the vast majority of data points throughout southern Viet Nam.

Herbicide application throughout the Aluoi Valley ceased in approximately 1970, 27 years prior to our sampling expeditions. The persistence of the 2,3,7,8-T4CDD congener is evident in our results, echoing conclusions of others who have performed blood investigations in Viet Nam (Schecter 1994b).

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* Note: CTZ II = 7696×10^3 ha; CTZ IV = 3797×10^3 ha (Westing 1984a).

It is of significance that males and females born after the cessation of hostilities have notable levels of 2,3,7,8-T4CDD in their blood (Figure 4.13). The suggestion is that the transfer of this contaminant is occurring to the younger generation through the food chain and through breast milk to infants.

Dioxin levels in males born post-war exceeded females born post-war (Figure 4.12). Levels in males >25 years of age also exceeded females >25 years of age. Males in both age categories appeared to have a greater affinity for dioxin contamination than females.

It was reported to the Hatfield team that males in the area have a tendency to forage away from their villages and "live off the land" for several days on hunting expeditions (*pers. comm.* Dr. Hoang Trong Quynh, 10-80 Committee, Ha Noi). These differences may have occurred because males ingested greater quantities of contaminated foodstuffs away from the village. The release of contaminants through breastfeeding of infants may have contributed to these differences, in addition to those possibilities noted above as suggested by Dr. Quynh.

The female post-war sample ranged in age from 12 to 25 years of age; however, the concentration of 2,3,7,8-T4CDD in this category was essentially comparable to the >25 year class (TEQ also). Given some of the female contributors to the post-war category were quite young (three were 12 years of age) and the 2,3,7,8-T4CDD concentration in this age category was essentially equal to that of the >25 years of age female class, the ingestion of local contaminated foods appears to be a reasonable explanation.

The 1997 data from A So show that 2,3,7,8-T4CDD contributed the highest proportion to the TEQ value of all data points presented (Figure 4.14). These high percentages strongly indicate that the 2,3,7,8-T4CDD detected in human blood originated from Agent Orange herbicide.

It is notable that the 1997 data stand out when viewed in relation to other southern Viet Nam data points. Whether or not the additional 5-10 years between the last series of samplings reflects further bioacummulation/biomagnification is a point of speculation. The Aluoi Valley is isolated with no industrial development and limited food stuffs, and that may be enhancing bioacummulation and biomagnification if contaminated foods are constantly being ingested with little choice for other sources of nourishment. In areas farther south, the ingestion of a wider variety of uncontaminated foods is highly probable, thus "diluting" the concentration of 2,3,7,8-T4CDD available for consumption, and reducing the potential for presence of this congener in blood.

Dai *et al.* (1995) state that high 2,3,7,8-T4CDD contamination in residents inhabiting areas near former airbases may have resulted from their close proximity to these bases and the warehouse and tank storage areas for Agent Orange.

Cecil (1986) states, for example, that the Bien Hoa airbase bulk storage facility could hold up to 90,000 U.S. gallons of herbicide; in addition, the premises contained a 55-U.S.-gallon drum storage area. Dai *et al.* (1995) also suggested that human contamination, near airbases in particular, occurred through the misuse of emptied chemical containers which were sold to locals to serve as depositories for food, rice, water, petroleum products, etc. A declassified document states:

> *"In early 1969 large numbers of shade trees in Da Nang appeared to be dead or dying. Garden plots in the city were also damaged. There were strong indications that the damage was caused by herbicides either by drift or leakage from spraying aircraft, or from herbicide drums brought into the city. Investigations ruled out the aircraft leakage or drifting spray. In every case of damage however, drums which were considered empty were either present or had been moved through the area. Herbicides are pumped from 55 gallon drums into the spray aircraft. The method of pumping leaves a residue of 2 to 3 gallons each drum. In the case at hand, the bungs were generally not replaced (or at best loosely replaced) and the drums were loaded onto trucks, hauled into Da Nang, (often dripping herbicide along the road), and sold to commercial concerns"* (*pers. comm.* U.S. Department of the Army, February 6, 1995: declassified documents entitled *"Accidental Herbicide Damage – Viet Nam"*).

The barrels were used to water trees and served as containers for motor bike fuel. This fuel when used discharged fumes that settled on trees, etc. It is reasonable to conclude that incidents of this nature could have occurred quite frequently near numerous bases in southern Viet Nam, thus providing an extraordinary route for eventual human contamination.

Cecil (1986) states that the U.S. Secretary of Health and Human Services reported the existence of 90 emergency jettisons of Agent Orange payloads during the Viet Nam war; of these, 41 were apparently over or near U.S. airbases and other military installations. Cecil further clarifies that these 41 emergencies near U.S. installations would almost always have involved jettisons off the end of runways at Bien Hoa, Tan Son Nhut, or Da Nang. The on-target jettisons were apparently the result of battle damage which would indicate higher than normal levels of Agent Orange were released over a given area.

Figure 3.1 introduced some comparative data regarding 2,3,7,8-T4CDD human blood levels in southern Viet Nam and other countries. Appendix A2.5 presents a tabulated summary of 84 sets of blood dioxin analyses representative of work-place levels (specific to type of work place), mothers and children of workers, some Viet Nam veterans, fish eaters, chemists, eaters of contaminated foods, certain cities/countries, controls, vegetarians/non-vegetarians, etc. These data (Appendix A2.5) are presented in order to enable a very general comparison of the levels of 2,3,7,8 – T4CDD determined in a number of other research studies.

Considering the 31 ppt level (2,3,7,8-T4CDD congener) in males > 25 years of age from A So (Aluoi Valley; Figure 4.13), the data in Appendix A2.5 indicate that of the 84 data sets presented, only ten exceed the 31 ppt level for older males. The ten higher values were for trichlorophenol plant workers, workers involved in a trichlorophenol accident, herbicide plant workers, chemical plant workers, male and female chemical factory workers, and offspring of chemical factory workers (i.e., highly exposed individuals).

Males >25 years of age had 2,3,7,8-T4CDD levels that exceeded 74 of the 84 data categories presented in Appendix A2.5. Males <25 years of age had 21 ppt, a value which was exceeded by only 11 individual analyses of the 84 presented in Appendix A2.5.

Males in both age categories sampled approximately 27 years following cessation of herbicide applications in the valley, are exhibiting 2,3,7,8-T4CDD levels well in excess of those recorded from the majority of workers/residents of industrialized nations, as summarized in Appendix A2.5. Exposure of the older males to Agent Orange during the Viet Nam conflict, in concert with a food chain that is made up in part of contaminated foods, probably has been instrumental in fostering/maintaining higher levels of this contaminant in the older generation and has resulted in increasing body burdens in the younger generation.

When comparing 2,3,7,8-T4CDD data from northern Viet Nam with A So males, marked differences are noted. Applying Ha Noi data in a comparison (Figure 4.13), A So males >25 and <25 years of age had 2,3,7,8-T4CDD levels which were (at a minimum, given the congener is expressed as <2.4 ppt) approximately 13 times and nine times the Ha Noi level, respectively. Employing Thanh Hoa data (also a non-sprayed area) in a similar comparison (Figure 4.13), yields an 11 times and seven times higher concentration in A So males. It should be noted that this comparison has its limitations; collection periods varied and age/sex were not segregated in the northern Viet Nam data. However, the gross comparison of 1997 data with historical values reveals substantial differences between the two regions of the country decades after the war.

Each blood analysis from A So consisted of pooled blood from 50 individuals. The process of pooling has the potential to mask higher levels of dioxin contamination that may have existed in some individuals within each age/sex category sampled. Similarly, lower dioxin levels may have existed on an individual basis, which would have effected a lowering of the pooled value. In order to obtain more information and improve the quality of this information, reducing the number in a pooled sample is desirable. This approach must be balanced against reducing the quantity of blood, which would have the effect of lowering the detection level during the dioxin analysis. Reducing the "N" value in a pooled sample would increase the significance of the dioxin value contributed by any given individual.

The fact that 27 years has elapsed since the direct application of Agent Orange to the Aluoi Valley is of significance; the persistence of this dioxin congener and its continuing movement through the food chain into local inhabitants is undoubtedly a major characteristic of the Aluoi Valley ecosystem. The relative isolation of the inhabitants of Aluoi Valley, lack of industrialization, and the abandonment of the A So base early in the war, indicates that the local environment is the principle conduit through which 2,3,7,8-T4CDD is being transported to humans in the valley.

During the course of studies in the Aluoi Valley, numerous observations were made regarding abnormalities in children and adults (e.g., Plates 4.24 and 4.25). The relationship, if any, of these conditions to human Agent Orange contamination was not the direct subject of this study.

Pesticides/Herbicides/PCBs

Soils

In terms of contaminant loading, particularly for reference soils, the Canadian Council of Ministers for the Environment (CCME) has established draft guidelines for "total DDT" (which includes metabolites) in agricultural soils at 500 ng/g for the protection of environmental health (*pers. comm.* Mr. S. Ouellet, Environmental Quality Guideline Specialist, Guideline and Standards Division, Environment Canada, Hull, Quebec).

Farmer's field soil in the reference area contained up to 15,000 ng/g of p,p'-DDT with metabolites of DDT (i.e., DDE and DDD) ranging from 62 ng/g to 2,500 ng/g for the DDEs and 290 to 1,900 ng/g for the DDDs. Farmer's field soil in the Aluoi Valley (A So) contained negligible levels of the DDDs, one DDE and one DDT. The airbase soils from Dong Ha contained more pesticide residue than farmer's field soils at A So. It is evident DDT levels in the Con Cuong region (i.e., Chi Khe) have far exceeded the CCME guideline. Other soils do not approach the levels noted at Chi Khe. Tables 4.5, 4.6 and 4.7 summarize these residues in soil.

Herbicides were not detected in any of the soil samples tested.

PCBs were detected only at the former airbases. This was probably related to the use of PCB-containing equipment and materials at these bases during the war.

Biological Tissues

The most notable pesticide residue detected in biological tissues was DDT and metabolites (i.e., in carp fat). The total DDT content (including metabolites) in the carp fat sample was 1094.3 ng/g.

Health Canada has established a guideline of 5,000 ng/g residue in fish tissues (Health Canada 1993). Therefore, tissue levels recorded in the Aluoi Valley do not exceed the Canadian threshold.

DDT residues were found in carp fat collected from A So but not in farmer's field soils. However, these residues were detected in former airbase soils, suggesting perhaps that the area is not totally devoid of this contaminant whether it be transported to the area through atmospheric forces or through direct human activity.

The economic status of the people in the Aluoi Valley does not appear to be conducive to high pesticide use because of cost. Such was not the case in the Con Cuong region. As a result, the finding of higher pesticide residues in Con Cuong is not surprising, despite the limited scope of our study.

PCBs were not detected in any biological tissue tested.

Human Health

Aluoi Valley dioxin data from the Hatfield/10-80 Committee environmental study were provided to the 10-80 Committee in early 1998. Given the high contamination levels found in the A So commune, medical personnel from the 10-80 Committee and local health departments independently conducted a study on human health in A So and Huong Lam communes. The Huong Lam commune is situated immediately to the northwest of A So (Figure 4.4). Although epidemiological analyses relating present-day exposure of Agent Orange dioxin to human health effects were not the primary objective of our environmental food chain study, some preliminary results of this 10-80 Committee investigation have been included here for information. Results of the study were provided to Canadian project team members by the 10-80 Committee as unpublished data.

The study consisted of collecting herbicide exposure information, physical birth defects and general health data (e.g., intestinal disorders, diarrhea, liver inflammation, heart disease, asthma, urinary inflammation, etc.). Residents of each commune were interviewed to determine their exposure history and medically examined. Preliminary data indicate that the incidence of birth deformities in the A So and Huong Lam communes over the 1965-1995 period investigated was an order of magnitude greater than those rates determined in similar communes from northern (unsprayed) areas of Viet Nam. These data suggest there could be a direct relationship between environmental contamination with dioxin (including human blood) and birth defect rates. Vietnamese researchers have concluded this is the case.

The Vietnamese health study found that the general health patterns of people in A So and Huong Lam have the characteristics of a tropical region with a poor economy. Although a large quantity of general health data were collected, the study concluded that a cause-and-effect relationship could not be made between Agent Orange dioxin exposure and general health.

Establishing cause-and-effect relationships between exotic chemical contamination and negative effects on human health has been controversial in many jurisdictions. Dioxin effects, in general, and Agent Orange dioxin effects, in particular, have been very difficult to isolate and quantify in past studies in other regions of the world. However, recent birth defect data from Viet Nam suggest that obtaining hard scientific information to better establish the relationship between environmental contamination and some health effects is possible. These preliminary results, suggesting an order of magnitude difference between birth defect rates in the north and south, if confirmed, would indicate that the linkage between contamination levels and certain negative health effects in Viet Nam is strong.

Clearly, more epidemiological work must be undertaken in Viet Nam to explore and document human health problems identified by Vietnamese medical personnel. Based on environmental levels of Agent Orange dioxin contamination found during this investigation, there is an urgent and immediate need to carry out further medical evaluations and to design environmental contamination mitigation and rehabilitation plans in Viet Nam and other sprayed areas of Indochina (i.e., Cambodia and Laos).

5 RADARSAT REMOTE SENSING

INTRODUCTION

Areas in southern Viet Nam such as the Aluoi Valley, Quang Tri Province, Ma Da forest and Ca Mau peninsula experienced extreme changes in forest cover and land use during the war. Bombing and herbicide spraying made lasting visible changes in forest cover and land features. In the past 25 years, areas have been converted to agriculture, reforested, or left barren. The recovery of land and subsequent land use changes following the war has resulted in complex patterns of land features, which are well suited for monitoring by remote sensing. Hatfield scientists found that RADARSAT and other remote sensing imagery is very useful in assessing such war-related impacts.

This section provides a selection of imagery that may be integrated with ground-based herbicide data to provide a larger-scale assessment of herbicide impacts. The imagery was used for interpretation with ground-truthing studies, supporting historical, topographic and land use information, and aid from Vietnamese forest specialists.

Foresters have used air photos and earlier remote-sensing imagery to assess war damage to Viet Nam's forests (Ashton 1986, Boi 1994; Ha and Boi 1994). Currently, the Viet Nam Forest Inventory and Planning Institute (FIPI) conducts national forest mapping and inventory on a project-by-project basis with the aid of some satellite imagery (Landsat TM and SPOT-XS), extensive field visits, and limited aerial photography. Agency experience in Viet Nam with RADARSAT data was initiated by Hatfield Consultants Ltd.

Objectives for the RADARSAT remote sensing work included:

- collection of RADARSAT imagery of Aluoi district and other areas of southern Viet Nam expected to show a diversity of forest cover, land use, and changes in land use as residual effects of the Viet Nam war and subsequent recovery;
- acquisition of secondary sources of land cover information regarding the area (e.g., topographic, forest cover and land use maps, aerial photography, other remote sensing imagery [Landsat/SPOT]) for evaluation and comparison with RADARSAT images;
- interpretation of RADARSAT images with the aid of these secondary data sources, aided by Vietnamese remote sensing and forest mapping experts;
- evaluation of RADARSAT image utility in identifying specific land cover features (e.g., forest cover and type, water bodies, agricultural crops, roads, human settlements, etc.) and comparison with other remote sensing imagery where possible; and

- assessment of RADARSAT synthetic-aperture-radar (SAR) imaging as a tool for environmental monitoring and management in Viet Nam, and comparison of RADARSAT's abilities with non-radar-based remote sensing technologies.

Radar remote sensing provides near real time, synoptic views necessary to map regional land cover features. It can also provide validations or supporting information for field data collection. Given SAR is an active microwave system, it can provide weather-independent imaging (e.g., through wet season cloud cover) by day or by night.

Key attributes of RADARSAT include:

- ability to acquire imagery from different incidence angles, among which high angles (>50° incidence; e.g., RADARSAT S6, S7, F4, F5) are considered best for forest cover;

- all-weather viewing through clouds and a frequent revisit cycle, permitting timely monitoring (existing optical satellites, e.g., SPOT/Landsat, are unable to image through clouds and are hampered by lengthy repeat cycles);

- on-board tape recorders and an international ground station network, ensuring global coverage;

- ability to merge data from several dates into a false-colour composite to illustrate changes over time; and

- a range of available support services, such as priority and urgent programming, rush and near real time processing and electronic data delivery.

RADARSAT is not the only SAR sensor in orbit, however, it is the most flexible and the only one oriented towards commercial use. Unlike the ERS 1 & 2 (European experimental SAR satellites), SPOT and Landsat satellites, RADARSAT is equipped with an On-Board-Recorder (OBR); data can be downlinked directly to a local station or recorded for later downlink to Canadian facilities.

STUDY DESIGN AND METHODS

A phased approach was taken for the RADARSAT project. Imagery was acquired in areas sprayed with herbicides according to the HERBS database (Figure 1.1).

In the first phase (April 1996 to February 1997), the technical scope of the project was defined, specific objectives and tasks were assigned, and preliminary RADARSAT images were obtained of the Aluoi Valley, Hue, and Ma Da forest. Ca Mau peninsula imagery was collected during the second phase. Preliminary images, taken in July and August 1996 during monsoon season in central Viet Nam, were examined to determine the ability of RADARSAT to identify specific land cover features such as forest cover, crop cover, land use, roadways, etc. This preliminary analysis suggested that RADARSAT was effective for highlighting differences between various types of land cover and forest type.

Field trips were undertaken in March to May 1997 to inspect areas for which imagery from the first phase was collected. Hand-held Global Positioning Systems (GPS) were used to identify the field team's locations. Through comparison of visible land and forest cover features with the georeferenced RADARSAT images of the area, Hatfield scientists assessed whether the RADARSAT imagery was successful at highlighting specific land cover features. Results were positive, with many forest types, land, and coastal features distinct in the imagery.

An important aspect of the fieldwork was discussions with appropriate government organizations and individuals for acquiring supporting information and expertise to aid in the interpretation of RADARSAT imagery during later project phases. Based on results of field studies, final decisions were made regarding areas for which more image acquisition was warranted.

In June 1997 to February 1998, the major technical phase of the RADARSAT work was completed. Objectives of this phase included:

- obtaining new RADARSAT imagery of selected heavily sprayed areas of southern Viet Nam;
- collecting and digitizing secondary information (e.g., basemaps, herbicide application data, land use information) to be used in interpreting RADARSAT imagery;
- digital image processing of RADARSAT scenes and supporting remotely-sensed data (e.g., SPOT imagery);
- interpretation of RADARSAT imagery through comparison with secondary data sources, discussions and image interpretation with remote sensing staff in Viet Nam and ground-truthing of Aluoi/Hue, Ma Da and Ca Mau areas;
- detailed assessment of the capabilities of RADARSAT imagery to identify specific land and forest cover features; and
- evaluation of the utility of RADARSAT imagery as a tool in on-going environmental monitoring and management in Viet Nam.

The Hatfield (1998) report on this work is available through the Hatfield Consultants Ltd. website (www.hatfieldgroup.com).

RESULTS

The following table lists the RADARSAT images collected during Phases I and II that are the most relevant to this Agent Orange dioxin assessment report.

Representative RADARSAT images collected during Phases I and II.

Study Area (Coverage)	Beam Mode – Incidence Angle	Look Direction	Orbit Number	Collection Date
Quang Tri & Hué province	Standard-7	Ascending	6230	January 13, 1997
Quang Tri & Hué province	Standard-7	Ascending	10689	November 21, 1997
Aluoi valley	Fine-3	Ascending	3929	August 5, 1996
Ma Da upland forest	Standard-7	Ascending	4072	August 15, 1996
Ca Mau peninsula	Standard-7	Descending	9352	August 19, 1997

The following table contains a list of the supporting Landsat and SPOT-XS (multi-spectral) images collected for comparison and/or integration with the RADARSAT imagery.

Supporting Landsat and SPOT-XS images collected.

Study Area (Coverage)	Type of Imagery	Media Format	Image Number	Collection Date
Aluoi valley	SPOT-XS	Digital file	274-318	March 5, 1996
Ma Da upland forest	SPOT-XS	Digital file	276-327	March 5, 1996
Ca Mau province	Landsat-1 MSS	Digital file	LM1135054007300390	January 3, 1973

The remote sensing imagery is presented in the form of nine Plates. The red dots on these images represent global positioning system (GPS) readings taken by Hatfield/FIPI ground crews while carrying out ground truthing during surveys in each area.

- Plate 5.1 Overview, Aluoi Valley (1:250,000, RADARSAT S7).
- Plate 5.2 Aluoi Valley (1:250,000, SPOT-XS multi-spectral).
- Plate 5.3 Detail, Northern Aluoi Valley (1:70,000, RADARSAT F3/SPOT-XS).
- Plate 5.4 Quang Tri Province and Former DMZ (1:250,000, RADARSAT S7).
- Plate 5.5 Dong Ha/Con Thein (1:100,000, RADARSAT S7/S7 multi-temporal).
- Plate 5.6 Overview, Ma Da Upland Forest (1:250,000, RADARSAT S7).
- Plate 5.7 Ma Da Upland Forest (1:100,000, SPOT-XS).
- Plate 5.8 Overview, Ca Mau Peninsula (1:250,000, RADARSAT S7).

- Plate 5.9 Ca Mau Peninsula (1:250,000, Landsat-1 MSS).

Two RADARSAT images of the Aluoi Valley are presented: a S7 (high incidence angle), which extended as far south as Aluoi, and a F3 (fine mode). In addition, a SPOT-XS scene of the valley was acquired for comparison and combination with RADARSAT data. Ground-truthing was undertaken in November and December, 1997 for the remotely sensed study areas, by Hatfield and FIPI staff who also collected samples of soil, sediment, fish, livestock and human blood for dioxin analyses. RADARSAT imagery was used as one tool to determine dioxin-sampling locations.

Plate 5.1 is an overview of Aluoi in RADARSAT standard mode S7 on which is superimposed the yellow aerial spray lines, from the HERBS database, and the red ground-truthing GPS way-points. The Aluoi area, in general, is relatively mountainous with the valley extending in the plate from A So to Ta Bat to Aluoi and beyond. The region was heavily sprayed.

Plate 5.2 is a SPOT-XS image of the area. Forest cover, particularly in the hills and in steep terrain, is easily discernable. Vegetation densities can be discerned to some extent, with dense forest appearing deeper red than poor forest and barren areas. Linear barren features in the hills bordering the Aluoi Valley, from herbicide application, are visible. Barren areas, and possibly slash-and-burn agriculture in the Ap Bia area (see Plate 5.1) are also evident.

Plate 5.3 is a fusion of the SPOT-XS and RADARSAT F3 images, showing the northern Aluoi area. Addition of the RADARSAT data to the SPOT data provides greater resolution of river channel morphology, reservoirs, and the road along the valley bottom, but reduces resolution of forest cover types in steeper terrain. Discrimination of rice is not aided by addition of the RADARSAT F3; this is because, although topography of surrounding hills is more detailed, it is no more interpretable than the standard mode scene. Rice paddies in this area, visible at 1:250,000 in the January S7, are difficult to discern from surrounding barren and uncultivated (FIPI 1991) land. Combination of the SPOT image with properly-timed single-pass or multi-temporal fine mode imagery would likely achieve this goal; however, this fusion would require a detailed digital elevation model for rectification, adding to the cost and complexity of this task.

Barren grasslands resulting from herbicide application continue to be a residual effect of the war on the people and environment of the Aluoi Valley. Much of this remaining damage occurred in steep terrain, and could not be quantified using RADARSAT technology.

Plate 5.4 is an overview of Quang Tri Province in RADARSAT standard mode S7 (January 1997) on which is superimposed the yellow aerial spray lines and red ground-truthing GPS way-points. The major rivers in this image are clear. Clear distinctions exist between the mountainous areas and flat plains.

Plate 5.5 is a multi-temporal RADARSAT S7/S7 image of the town of Dong Ha (lower right), Cam Lo river, Con Thien area (centre), and the former demilitarized zone DMZ (top). The November 1997 image was ordered to establish whether multi-temporal scenes would yield better discrimination of different land cover features than a single-pass scene. This was the case. Several features are immediately visible.

Purple areas are rice paddy. In the January image, rice fields returned weak (i.e., dark) radar backscatter (likely due to water in the rice paddies), and are difficult to distinguish from other features of similar backscatter, such as the large arrowhead-shaped feature along the eastern edge of the image. In the November image, rice fields return a strong (i.e., bright) radar backscatter (likely due to mature rice with little water), and are difficult to distinguish from towns, forests, and croplands which also returned relatively strong backscatter. Combination of these two images into a multi-temporal scene, however, allowed clear delineation of areas of rice cultivation. The arrowhead-shaped formation, dark red in the scene, is an area of relatively barren, white sand dunes.

The war destroyed most of the natural forests in the lowlands of Quang Tri, leaving barren fields of grasses and scrub. Intensive efforts by the Vietnamese to revegetate this area continue, but are hampered by poor soil conditions (*pers. comm.* Mr. Phung Tuu Boi, FIPI.). The area of most intensive forest plantation development has occurred east and west of the three reservoirs visible in the image (two of which were recently constructed). These forest plantations appear as a lighter, irregular area in the upper-centre of the image. Various roads among the plantations are visible at the western edge of this feature. Trees planted include eucalypts, rubber, cashew, and pine. Darker (red) areas surrounding this patch of bright return, visited by Hatfield staff in November 1997, were predominately barren, with sparse to dense growth of tall grasses and few if any trees. Some small plantations of young eucalypt were observed in these areas. Barren areas in the immediate vicinity of the lower two reservoirs in this scene also appear dark red compared with the surrounding features (Plate 5.5, facing page).

An interesting difference between the two images used to compose this multi-temporal scene is visualized in the multi-date scene as the darker, slightly purple, rectangular area in the western centre of the area of brighter return (plantation). This area yielded clearly different return in the January 13 image, but is barely distinguishable in the November 21 image (Plate 5.5, facing page). Ground-truthing along the southern edge of this feature in November indicated that it was planted with young rubber, with more mature rubber plantation and cashew plantation south of it.

Other visible features include the reservoirs (differences in water levels between the different dates are apparent in the multi-temporal scene), and major human settlements, including the villages of Dong Ha, Cam Lo, and Gio Linh. Dry-land crops of various types are distinguished from rice and generally from dense forest by their strong backscatter return, and sometimes by a yellowish tone, indicating stronger return in the January than in the November image – the opposite of rice.

Plate 5.6 is an overview of Ma Da upland forest in RADARSAT standard mode S7 on which are superimposed the yellow aerial spray lines and the red ground-truthing GPS way-points. The large reservoir in the lower right corner is the Tri An reservoir, created in the early 1980s. Northwest of the Tri An reservoir is the smaller Ba Hao reservoir. The Song Be river is visible in the lower left quadrant of the scene. The roughly round, flat-looking area northwest of the Tri

An reservoir is the Ma Da forest proper. The small Ma Da River flows approximately northeast-southwest through this area, flowing into the Song Be river.

The Ma Da Forest Enterprise is responsible for the management of the forest south of the Ma Da River, while the Phu Binh Forest Enterprise is responsible for forests north of the river. The area south of the river was more actively rehabilitated and reforested after the war, with a mix of eucalypt, rubber and teak. The area north of the river was sparsely populated, and therefore primarily left to regenerate naturally without active rehabilitation.

Rang Rang, the site of a USVN airfield during the war, and now site of a very small village, is located on the Ma Da River, in the approximate centre of the forest, along a seasonal road which connects Tri An with the village of Dong Xoai north of the forest.

Plate 5.7 displays a SPOT-XS scene of the Ma Da forest in which the Ma Da River roughly bisects the image from top-right to bottom-left. Rang Rang is near the centre of the scene, along the road from the Ba Hoa reservoir below. Different land uses are apparent in the northwest corner of the scene; these are likely plantations of rubber, cashews and eucalypt, the species most frequently replanted in this area.

Of most interest are the north-south linear features visible to the north of the Ma Da River. The areas surrounding these "lines" are composed of low, dense, naturally-regenerated forest, with occasional large *Invingia* trees, which were resistant to herbicides, standing well above the rest of the forest canopy (Plate 5.7, facing page). Land cover within the lines themselves is generally uncultivated grassland. There is some scattered cultivation and new plantation forestry north of Rang Rang, and near the small "exclamation point"-shaped reservoirs in the centre-left of the scene, but typically these lines support barren grasslands (Plate 5.7, facing page).

Generally, SPOT-XS imagery was very effective at showing breaks in forest cover and linear grasslands. The precise north-south direction of these grasslands line up with herbicide application flight patterns during the war in this area.

Plate 5.8 is an overview of Ca Mau peninsula in RADARSAT standard mode S7 on which is superimposed the yellow aerial spray lines and red ground-truthing GPS way-points. North of the Cau Lon River, the dark areas represent shrimp farms; the lighter areas north of the shrimp farms are rice growing areas. Shrimp farms are also evident south of the Cau Lon River. The canal systems are evident throughout the image.

Plate 5.9, a Landsat-1 MSS image of Ca Mau from January 1973, was acquired from the U.S. Geological Service archives, for change detection analysis. This scene shows the extent of herbicide damage in 1973. Areas of herbicide application are very clear in this image – the natural mangrove forest cover (dark red) is non-existent in the spray lines; barren mangrove channels are visible in these areas. The northern extent of natural mangrove forest, bordering rice-growing areas, is clear as the boundary between dark red (mangrove) and pink (rice). Little human development in the mangrove area is evident, although some regular-shaped clearings (perhaps logging) are visible near the northern edge above the Cau Lon River.

DISCUSSION

Our objective was an evaluation of the utility of RADARSAT imagery when used in combination with field dioxin sampling in an integrated assessment of residual environmental effects of herbicide spraying. These effects were evident during regional ground-truthing in November and December 1997, particularly large-scale changes to land-use and land-cover. In some cases, however, differentiation between changes resulting directly from warfare and those caused by population increases (Viet Nam's population has doubled since the war) and more farming and forest harvesting was difficult.

In the Aluoi Valley, war-related damage remains clearly visible with barren grasslands still occupying large areas formerly covered by native forest. Despite significant efforts by the Vietnamese government to establish plantation forests, much of central Viet Nam remains covered with scrubby grassland, unproductive for humans or wildlife (Quy 1992).

As a tool for feature detection, RADARSAT imagery provided much useful information. Single-date data provided information on some forms of agriculture if timed properly, land cover (e.g., forest cover vs. barren areas) and patterns of settlement. Land cover data were lost in images of even moderately rough terrain. The ability to interpret images and extract useful information was, therefore, greater in flat areas such as the floor of the Aluoi Valley, compared to the surrounding hilly terrain where important land-cover information was not detectable.

Multi-temporal composite images were effective for monitoring seasonal changes on croplands, floodplains, and forests, and generally reduced the effects of image collection conditions on interpretation of scenes. Either single-date or multi-temporal imagery would be useful for developing or updating digital base maps for environmental surveys. Digital land cover maps based on early 1990s Landsat-TM imagery, did not accurately represent land cover features visible in 1996 and 1997 RADARSAT imagery, or 1997 ground-truthed information.

Multi-temporal RADARSAT data were more effective in discriminating specific types of agricultural land uses (e.g., rice, dryland cropping) than optical imagery (Hatfield Consultants Ltd. 1998). RADARSAT's ability to discriminate between different land uses is most evident in the multi-temporal images that discriminated between varied cultivated areas and surrounding forests. Multi-temporal RADARSAT imagery is highly effective in construction of basemaps of land cover and use in environmental assessments on relatively level terrain.

In Aluoi, monitoring and controlling illegal forestry activities should be an important environmental task. Satellite imagery can inform regulatory agencies on events in remote areas. Optical imagery is poorly suited to this task due to its inability to record through cloud cover. In addition, RADARSAT could be used to update land-cover maps over large areas on a regular and cost-effective basis. These maps frequently form the basis for environmental management plans. Standard-mode RADARSAT imagery provided sufficient resolution to discriminate land use features of interest and covered large geographic areas such as monitoring urban development.

Although other remote sensing techniques can be used effectively for many of the above applications, poor atmospheric conditions throughout the region may result in unacceptably long delays before suitable data can be acquired. This provides RADARSAT with a significant advantage.

CONCLUSIONS

The RADARSAT project provided useful information regarding its effectiveness as a tool for environmental impact assessment, monitoring and mitigation plans:

- sprayed areas can be detected using satellite imagery (RADARSAT and optical); these areas reliably yielded dioxin contamination results from samples collected during ground-truthing;
- in both low relief and hilly sprayed areas, optical (SPOT) imagery was effective;
- RADARSAT was not effective at providing land-cover information in areas of hilly, rough terrain;
- RADARSAT was marginally effective for vegetation assessments in sprayed areas, however, such features can be detected if RADARSAT data are fused with optical data;
- very active reforestation and the naturally rapid ecosystem processes of mangrove forests (e.g., Ca Mau) has led to recovery from spraying in some former mangrove areas;
- many upland areas (e.g., Aluoi) remain largely unforested as opportunistic, spray-resistant grass species have hindered forest succession processes; and
- there is good potential for use of satellite data for monitoring forest ecosystem recovery.

6 CONCLUSIONS

1. Soils contaminated with dioxin, originating from the herbicide Agent Orange, were found at a small former U.S. airbase and airstrip situated in A So commune in the Aluoi Valley, Viet Nam. Levels found would probably result in such an area being declared a "contaminated site" if it was located in most western jurisdictions. Agent Orange dioxin was also detected at lower levels in soils collected from farmer's fields.

2. Dioxin contamination related to Agent Orange was found in grass carp growing in fishponds excavated out of the terrain in the vicinity of the former Aluoi Valley airbase. Levels found would trigger a consumption advisory process (i.e., recommendations on maximum human consumption levels) and possibly prohibitions against consumption if they were from a location in Canada or other western jurisdictions.

3. A consistent pattern of food-chain contamination by Agent Orange dioxin was found in the airbase area which included soils, fishpond sediment, cultured fish, ducks and humans.

4. Other areas sampled in the Aluoi Valley exhibited Agent Orange dioxin levels below those considered threshold values in western jurisdictions. However, a more comprehensive dioxin sampling program may find other contaminated "hot spots" in the area. Agent Orange dioxin contamination, accumulation and magnification of levels found in soils and fishpond sediment could occur in other areas of Viet Nam, as illustrated by the A So data. Given data from the Ma Da region, the existence of other "hotspots" in Viet Nam is likely.

5. Relatively high levels of dioxin (particularly the 2,3,7,8-T4CDD congener, characteristic of Agent Orange) were found in human blood of populations living near the former A So airbase in the Aluoi Valley. People living in this isolated region who were born after the war also possessed high dioxin levels relative to unsprayed areas of northern Viet Nam, indicating a continuing process of dioxin uptake caused by contamination of the food chain.

6. Human health data collected in A So and adjacent Huong Lam communes by Vietnamese medical personnel, indicate that visible physical birth defect rates are an order of magnitude higher in these communes than in similar communes in northern unsprayed Viet Nam. The data are suggestive of a direct relationship between levels of Agent Orange dioxin contamination in the environment and effects on human health. Further studies by a multinational medical team of specialists familiar with assessing dioxin health issues should be carried out to confirm this relationship.

7. Since Agent Orange spraying was particularly heavy in the vicinity of former U.S. military installations (airbases, fire support bases, naval bases, etc.), the environmental contamination findings indicate that such areas may still contain contaminated soils and food chain components leading to significant human exposure and uptake. This is particularly likely

near major former U.S. airbases where large quantities of herbicides were transported, stored and/or handled (e.g., Bien Hoa, Tan Son Nhut, Da Nang).

8. Agent Orange and other herbicide spraying activities during the war resulted in dramatic land use changes in southern Viet Nam. Large areas of formerly forested land have been replanted with agriculture plantations or developed for shrimp farming.

9. Large areas of former upland and mangrove forested land once affected by herbicide spraying, continue to be affected by human activities involving the utilization of dead vegetation for lumber and firewood. Forested land continues to be affected by human activities.

10. Areas of coastal mangrove forest in the Rung Sat (Saigon River delta) and Ca Mau (Mekong River delta) have been rehabilitated by Vietnamese agencies. Many bird and animal species are returning to these areas. Some areas of the herbicide-affected former upland forest have been rehabilitated, but most of these areas remain as barren wasteland which has been invaded by coarse grass species that prevent natural forest regeneration. Vietnamese government and community agencies have ambitious forest rehabilitation programs at the planning stages. The success of the programs is limited by financial resources.

7 RECOMMENDATIONS

1. A public health protection plan is required for the A So area to ensure local people do not ingest foods contaminated with Agent Orange dioxin, nor are exposed through other routes. The consumption of high lipid content foods (e.g., fish fat) from contaminated areas should be avoided. Plant foods grown beneath the surface of the soil should be washed thoroughly with the outer skin removed prior to cooking/consumption to remove potentially contaminated soil.

2. Decontamination of soils by high temperature incineration is too expensive to be a realistic mitigation technique in Viet Nam at this time. Other mitigation plans are required to decontaminate or isolate areas presently contaminated with Agent Orange dioxin, such as the former A So airbase, to reduce human exposure. Temporary mitigation methods such as increasing the importation of marine fish species and, if necessary, other food from non-contaminated areas should be considered.

3. Additional blood sampling and testing should be performed throughout the Aluoi Valley to determine whether the high dioxin levels recorded in humans from A So occur in other areas of the valley, or whether this is an isolated data set related specifically to inhabitants living in close proximity to the former airbase.

4. Further assessments of dioxin contamination are required near all former U.S. military bases/facilities in Viet Nam, where use/storage of Agent Orange during the war likely occurred, to determine the level of Agent Orange related dioxin contamination and reduce human exposure. Studies of other geographical areas in Viet Nam over which heavy Agent Orange spraying occurred (aerial and land based applications) are also required. Such studies should consist of comprehensive food chain assessments, including humans.

5. Where additional sites are identified as being contaminated with dioxin, environmental impact mitigation and public health protection plans should be developed and implemented.

6. Studies of human health should be carried out in communes / villages near areas where soils or the human food chain are found to be contaminated with Agent Orange dioxin. Comprehensive epidemiological studies are required in Viet Nam if the relationship between environmental contamination with Agent Orange dioxin and human health effects is to be better determined.

7. If higher than normal birth defects, cancers or other health effects are found to occur in contaminated areas, special health clinics or treatment centers should be established to treat people affected by Agent Orange dioxin contamination. In the Aluoi Valley, the existing health clinic at A Ngo should be consolidated and improved to support adjacent villages, rehabilitate any handicapped people and provide advice to local people on health issues related to dioxin contamination.

8. Where clearing programs for unexploded ordnance are underway, parallel studies on soil contamination should be carried out to ensure re-disturbance of contaminated soils in these areas does not result in the creation of unacceptably high dioxin levels through re-mobilization in the environment. Such disturbance could make dioxin more accessible to elements in the local food chain and humans.

9. Sediment cores should be collected and analyzed from coastal areas which drain heavily sprayed regions or major former U.S. military bases in southern Viet Nam. Sediment core analyses in British Columbia (Canada) have shown stratified deposition of dioxins over time. Activities such as dredging or trenching in deposition areas could resuspend dioxin into the water column and potentially into the food chain.

10. Although the general areas of impact of Agent Orange on upland forests are known, thorough inventories, delineation, and updating of deforested areas are desirable. Satellite technology involving remote sensing imagery would be the most cost-effective way of carrying this out.

11. Vietnamese forest rehabilitation scientists have developed sound techniques for rehabilitating upland forests in areas sprayed with Agent Orange in southern and central Viet Nam. Some upland forest rehabilitation is now taking place in the country. These activities should be expanded significantly with funding from international agencies. Community forestry projects and flora/fauna biodiversity programs should be integral to these upland forest rehabilitation efforts. Programs have been successful in other regions of Viet Nam where local people have been given ownership and management control of land and forest areas in return for commitments not to destructively cut or burn forest areas for farmland. Such undertakings could include planting trees for lumber and industrial use and managing grasslands for livestock. The government of Viet Nam is prepared to provide the necessary financial and temporary food source support for families willing to participate in such forest rehabilitation programs.

12. Viet Nam, with its heavily sprayed areas in the south and reference areas in the north where no spraying took place, represents an excellent site for study of human health and environmental effects caused by exotic chemicals such as Agent Orange dioxin by scientists from the international community. Present world standards for soil and human food contaminated with dioxin represent only best estimates for human health safety. However, billions of dollars of industrial investment decisions, clean-up requirements and human health protection decisions are being based on these estimates. These standards would be more effective and credible if they were based on more comprehensive, hard scientific data. Viet Nam may be considered one of the best locations in the world to find solutions to the many questions and concerns regarding dioxins in the environment and their effects on human health.

13. Based on the levels of environmental contamination by Agent Orange dioxin found during this investigation, there is an urgency to carry out further programs of the nature outlined above to reduce the risk to human health posed by contaminated sites in Viet Nam.

The grave environmental problems can be solved. The resource base can be recovered and the Vietnamese people do have the energy, discipline and resourcefulness to beat these problems...

General Giap
(cited in Kemf 1988)

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Tables

Table 1.1 Summary of project funding/in-kind agencies, programs, program objectives and program reports.

Agency	Program	Program Objectives[1]	Report Titles[2]
1. Canadian International Development Agency (CIDA)	CIDA Inc. Canadian Project Support Facility (CPSF)	1. New joint venture staff training. 2. Environmental assessment technology transfer.	Joint venture environmental and aquaculture services company Bangkok, Thailand Project Support Facility Report.
2. Canadian International Development Agency (CIDA)	Viet Nam Short-term Retraining Fund (VSTRF)	1. Improve Vietnamese dioxin field sampling and analysis laboratories capabilities.	Building Dioxin Field sampling and Laboratory Capability in Viet Nam Project Report.
3. Environment Canada	International Environmental Management Initiative (IEMI)	1. Improve Vietnamese dioxin field sampling and analysis laboratories capabilities.	Building dioxin field sampling and laboratory capability in Viet Nam Project Report.
4. Canadian Space Agency (CSA)	RADARSAT User Development Program (RUDP)	1. Provide support for HCL and Vietnamese staff to learn how to use RADARSAT satellite remote sensing imagery in environmental assessment. 2. Test the resolution ability of RADARSAT imagery of environmental features in Asia.	Using RADARSAT Imagery to Assess Residual Environmental Effects of the Viet Nam war (1961-1975).
5. Revenue Canada	Scientific Research and Experimental Development expenditure (SRED) program	1. Assist Canadian companies to develop new technology through R&D.	SRED program R&D project reports.
6. Hatfield Consultants Ltd. (HCL)	1. Staff training programs 2. Significant in-kind contribution of personnel time and logistics costs	1. Contribution to the dioxin contamination study. 2. Assisting staff in gaining Indochina working experience. 3. Assisting staff in learning new environment assessment technology (i.e., RADARSAT).	HCL staff authored this study report and the reports listed above.
7. 10-80 Committee (Viet Nam)	1. Staff training program 2. Significant in-kind contribution of personnel time and logistics support	1. Contribution to the dioxin contamination study. 2. Assisting staff in learning new environmental assessment technology.	10-80 Committee staff reviewed and contributed to this study report.
8. Forest Inventory and Planning Institute (FIPI) (Viet Nam)	1. Staff training program 2. Significant in-kind contribution of personnel time and logistics support	1. Contribution to the dioxin contamination study. 2. Contribution to the RADARSAT imagery use project. 3. Assisting staff in learning new environmental assessment technology.	FIPI staff reviewed and contributed to this study report and RADARSAT report.

1 In addition to utilizing program data to assess environmental impact of herbicide spraying during Viet Nam war.
2 Reports produced on results of the program in addition to this study report.

Table 4.1 Sample media collected from Viet Nam, January 1996 and exported to Canada. Samples analyzed for dioxins/furans, select pesticides, herbicides and PCBs.

District	Commune	Sample ID #		Sample Type	Site Type	Analyzed For				
		Vietnam	HCL			Dx/Fn	Pest.	PCB	Herb.	not run
Aluoi	A Ngo	VN9605	29	bomb crater soil (0-10cm)	exposed	✓				
Aluoi	A Ngo	VN9613	31	bomb crater soil (10-30cm)	exposed	✓				
Aluoi	A Ngo	VN9619	35	fish pond sediment	exposed	✓				
Aluoi	A Ngo	VN9618	42	carp liver	exposed	✓				
Aluoi	A Ngo	VN9633	257	duck liver	exposed					✓
Aluoi	A Ngo	VN9649	217	pig liver	exposed					✓
Aluoi	A Ngo	VN9603	15	manioc root	exposed	✓				
Aluoi	Hong Thuong	VN9632	50	soil (0-10cm)	exposed					✓
Aluoi	Hong Thuong	VN9607	52	soil (10-30cm)	exposed					✓
Aluoi	Hong Thuong	VN9609	68	carp liver	exposed					✓
Aluoi	Hong Thuong	VN9620	261	carp liver	exposed	✓				
Aluoi	Hong Thuong	VN9637	78	duck liver	exposed					✓
Aluoi	Hong Thuong	VN9606	46	manioc root	exposed	✓				
Aluoi	Hong Ha	VN9626	205	farmer's field soil (0-10cm)	exposed					✓
Aluoi	Hong Ha	VN9615	207	farmer's field soil (10-30cm)	exposed	✓				
Aluoi	Hong Ha	VN9635	209	fish pond sediment	exposed	✓				
Aluoi	Hong Ha	VN9623	242	carp liver	exposed	✓				
Aluoi	Hong Ha	VN9616	220	duck liver	exposed					✓
Aluoi	Hong Van	VN9625	92	farmer's field soil (0-10cm)	exposed					✓
Aluoi	Hong Van	VN9643	94	farmer's field soil (10-30cm)	exposed	✓				
Aluoi	Hong Van	VN9610	96	fish pond sediment	exposed					✓
Aluoi	Hong Van	VN9601	102	duck liver	exposed					✓
Aluoi	Son Thuy	VN9629	125	pig liver	exposed	✓	✓	✓		
Aluoi	Xa Nham	VN9612	114	farmer's field soil (0-10cm)	exposed					✓
Aluoi	Xa Nham	VN9631	116	farmer's field soil (10-30cm)	exposed	✓				
Aluoi	Xa Nham	VN9640	142	carp fat	exposed	✓				
Aluoi	Xa Nham	VN9611	134	duck liver	exposed					✓
Aluoi	A So	VN9634	165	soil (0-10cm)	exposed					✓
Aluoi	A So	VN9642	171	former airbase soil (0-10cm)	exposed	✓	✓	✓	✓	
Aluoi	A So	VN9622	173	former airbase soil (10-30cm)	exposed	✓	✓	✓	✓	
Aluoi	A So	VN9647	167	soil (10-30cm)	exposed					✓
Aluoi	A So	VN9602	169	fish pond sediment	exposed	✓				
Aluoi	A So	VN9650	177	A Sap River sediment	exposed	✓				
Aluoi	A So	VN9646	198	carp fat	exposed	✓	✓	✓		
Aluoi	A So	VN9614	197	carp liver	exposed	✓				
Aluoi	A So	VN9608	179	duck liver	exposed	✓				
Dong Ha	Dong Ha	VN9645	277	former airbase soil (0-10cm)	exposed	✓	✓	✓	✓	
Dong Ha	Dong Ha	VN9630	279	former airbase soil (10-30cm)	exposed	✓	✓	✓	✓	
Con Cuong	Chi Khe	VN9636	320	farmer's field soil (0-10cm)	reference	✓	✓	✓	✓	
Con Cuong	Chi Khe	VN9624	322	farmer's field soil (10-30cm)	reference	✓	✓	✓	✓	
Con Cuong	Chi Khe	VN9648	314	manioc root	reference					✓
Con Cuong	Con Cuong	VN9621	341	carp liver	reference	✓				
Con Cuong	Con Cuong	VN9644	338	duck liver	reference	✓				
Con Cuong	Con Cuong	VN9641	300	pig liver	reference	✓	✓	✓		

Table 4.2 Sample media collected from Viet Nam, November 1997.

District	Commune	Sample ID #	Sample Type	Shipped To Canada	Dioxin Analysis By[1]
Aluoi	Hong Thuong	97VN061	juvenile fish pond sediment (hatchery)	✓	
Aluoi	Hong Thuong	97VN062	juvenile fish pond sediment (hatchery)		
Aluoi	Hong Thuong	97VN063	adult fish pond sediment (hatchery)	✓	
Aluoi	Hong Thuong	97VN064	adult fish pond sediment (hatchery)		
Aluoi	A So	97VN051	former airbase soil (0-10 cm)	✓	ETC
Aluoi	A So	97VN052	former airbase soil (0-10 cm)		
Aluoi	A So	97VN053	former airbase soil (10-30 cm)	✓	
Aluoi	A So	97VN054	former airbase soil (10-30 cm)		
Aluoi	A So	97VN057	former airstrip soil (0-10 cm)	✓	ETC
Aluoi	A So	97VN058	former airstrip soil (0-10 cm)		
Aluoi	A So	97VN059	former airstrip soil (10-30 cm)	✓	
Aluoi	A So	97VN060	former airstrip soil (10-30 cm)		
Aluoi	A So	97VN055	bomb crater sediment	✓	
Aluoi	A So	97VN056	bomb crater sediment		
Aluoi	A So	97VN005	fish pond sediment (Pond #1)	✓	AXYS
Aluoi	A So	97VN006	fish pond sediment (Pond #1)		
Aluoi	A So	97VN007	fish pond sediment (Pond #2)	✓	AXYS
Aluoi	A So	97VN008	fish pond sediment (Pond #2)		
Aluoi	A So	97VN009	fish pond sediment (Pond #3)	✓	AXYS
Aluoi	A So	97VN010	fish pond sediment (Pond #3)		
Aluoi	A So	97VN011	fish pond sediment (Pond #4)	✓	AXYS
Aluoi	A So	97VN012	fish pond sediment (Pond #4)		
Aluoi	A So	97VN001	manioc field soil (0-10 cm)	✓	ETC
Aluoi	A So	97VN002	manioc field soil (0-10 cm)		
Aluoi	A So	97VN003	manioc field soil (10-30 cm)	✓	AXYS[2]
Aluoi	A So	97VN004	manioc field soil (10-30 cm)		
Aluoi	A So	97VN013	ploughed sweet potato field soil (0-10 cm)	✓	ETC
Aluoi	A So	97VN014	ploughed sweet potato field soil (0-10 cm)		
Aluoi	A So	97VN015	ploughed sweet potato field soil (10-30 cm)	✓	AXYS[2]
Aluoi	A So	97VN016	ploughed sweet potato field soil (10-30 cm)		
Aluoi	A So	97VN019	grass carp fat (Pond #1)	✓	AXYS
Aluoi	A So	97VN020	grass carp fat (Pond #1)		
Aluoi	A So	97VN023	grass carp fat (Pond #1)	✓	
Aluoi	A So	97VN024	grass carp fat (Pond #1)		
Aluoi	A So	97VN027	grass carp fat (Pond #2)	✓	AXYS
Aluoi	A So	97VN028	grass carp fat (Pond #2)		
Aluoi	A So	97VN031	grass carp fat (Pond #3)	✓	AXYS
Aluoi	A So	97VN032	grass carp fat (Pond #3)		
Aluoi	A So	97VN035	grass carp fat (Pond #3)	✓	
Aluoi	A So	97VN036	grass carp fat (Pond #3)		
Aluoi	A So	97VN039	grass carp fat (Pond #4)	✓	AXYS
Aluoi	A So	97VN040	grass carp fat (Pond #4)		

Table 4.2 cont'd.

District	Commune	Sample ID #	Sample Type	Shipped To Canada	Dioxin Analysis By[1]
Aluoi	A So	97VN018	grass carp liver (Pond #1)	✓	
Aluoi	A So	97VN022	grass carp liver (Pond #1)	✓	
Aluoi	A So	97VN026	grass carp liver (Pond #2)	✓	
Aluoi	A So	97VN030	grass carp liver (Pond #3)	✓	
Aluoi	A So	97VN034	grass carp liver (Pond #3)	✓	
Aluoi	A So	97VN038	grass carp liver (Pond #4)	✓	
Aluoi	A So	97VN017	grass carp muscle (Pond #1)	✓	
Aluoi	A So	97VN021	grass carp muscle (Pond #1)	✓	
Aluoi	A So	97VN025	grass carp muscle (Pond #2)	✓	
Aluoi	A So	97VN029	grass carp muscle (Pond #3)	✓	
Aluoi	A So	97VN033	grass carp muscle (Pond #3)	✓	
Aluoi	A So	97VN037	grass carp muscle (Pond #4)	✓	
Aluoi	A So	97VN048	human blood (females >25 yrs)	✓	AXYS
Aluoi	A So	97VN050	human blood (females 12-25 yrs)	✓	AXYS
Aluoi	A So	97VN047	human blood (males >25 yrs)	✓	AXYS
Aluoi	A So	97VN049	human blood (males 12-25 yrs)	✓	AXYS
Aluoi	A So	97VN042	local chicken fat	✓	
Aluoi	A So	97VN043	local chicken liver	✓	
Aluoi	A So	97VN041	local chicken muscle	✓	
Aluoi	A So	97VN045	local duck fat	✓	AXYS
Aluoi	A So	97VN046	local duck liver	✓	
Aluoi	A So	97VN044	local duck muscle	✓	
Dong Nai	Rang Rang	97VN073	fish pond sediment (near Ba Hao Reservoir)	✓	ETC
Dong Nai	Rang Rang	97VN075	south of former airbase soil (0-10 cm)	✓	ETC
Dong Nai	Rang Rang	97VN076	south of former airbase soil (0-10 cm)		
Bien Phuc	Rang Rang	97VN077	north of former airbase soil (0-10 cm)	✓	ETC
Bien Phuc	Rang Rang	97VN078	north of former airbase soil (0-10 cm)		
Dong Nai	Rang Rang	97VN079	former airbase soil (0-10 cm)	✓	ETC
Dong Nai	Rang Rang	97VN080	former airbase soil (0-10 cm)		
Dong Nai	Rang Rang	97VN081	grass carp muscle (near Ba Hao Reservior)	✓	
Dong Nai	Rang Rang	97VN082	grass carp liver (near Ba Hao Reservior)		
Dong Nai	Rang Rang	97VN083	grass carp muscle (near Ba Hao Reservior)	✓	
Dong Nai	Rang Rang	97VN084	grass carp liver (near Ba Hao Reservior)		
Dong Nai	Rang Rang	97VN089	Ba Hao Reservior sediment	✓	ETC
Dong Nai	Rang Rang	97VN090	Ba Hao Reservior sediment		

[1]AXYS = AXYS Analytical Services, Sydney, British Columbia, Canada.
ETC = Environmental Technology Centre, Environment Canada, Ottawa, Ontario, Canada.
[2] Soil sample tested only for pesticide and PCB residues.

Table 4.3 Concentrations of dioxin and furan congeners in soil, fishpond sediment and animal tissues (pg/g dry weight [soils], pg/g wet weight [biological tissues]), central Viet Nam, January 1996.

Sample Location and Type	Sample ID	Polychlorinated dioxin/furan congener concentration (pg/g)													
		2,3,7,8-T4CDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-T4CDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF	Total TEQ	% 2,3,7,8-T4CDD of TEQ
A Ngo, Aluoi valley (Exposed)															
Bomb crater soil (0-10cm)	VN9605	1.1	2.0	0.5	3.9	26	830	ND	0.8	0.1	0.5	0.5	1.0	2.3	47.8%
Bomb crater soil (10-30cm)	VN9613	0.9	1.2	ND	3.0	27	950	ND	0.5	0.1	0.2	0.5	0.9	2.1	42.9%
Fish pond sediment	VN9619	5.3	7.7	6.3	9.7	35	880	0.2	0.8	ND	0.3	ND	ND	6.8	77.9%
Carp liver	VN9618	1.0	1.5	0.4	ND	ND	1.0	0.4	2.6	1.3	ND	ND	ND	1.2	83.3%
Manioc root	VN9603	ND	ND	ND	ND	ND	1.1	ND	ND	ND	ND	ND	ND	0.2	0.0%
Hong Thuong, Aluoi valley (Exposed)															
Carp liver	VN9620	1.6	1.6	ND	ND	ND	1.6	0.7	1.1	0.9	ND	ND	ND	1.9	84.2%
Manioc root	VN9606	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	0.0%
Hong Ha, Aluoi valley (Exposed)															
Farmer's field soil (10-30 cm)	VN9615	1.7	1.9	ND	2.9	2.7	48	0.2	0.5	0.3	ND	ND	ND	2.1	81.0%
Fish pond sediment	VN9635	0.3	0.3	ND	0.3	1.1	18	ND	ND	ND	ND	0.1	ND	0.4	75.0%
Carp liver	VN9623	0.3	0.6	ND	1.6	3.9	4.0	0.3	1.1	1.6	1.1	0.6	ND	0.5	60.0%
Hong Van, Aluoi valley (Exposed)															
Farmer's field soil (10-30cm)	VN9643	0.7	6.9	3.0	16	42	1700	ND	0.4	ND	ND	ND	ND	2.9	24.1%
Son Thuy, Aluoi valley (Exposed)															
Pig liver	VN9629	ND	ND	ND	0.4	17	300	ND	ND	0.6	3.4	7.2	2.7	1.3	0.0%
Xa Nham, Aluoi valley (Exposed)															
Farmer's field soil (10-30cm)	VN9631	4.3	6.5	3.9	6.6	9.9	230	ND	ND	ND	ND	ND	ND	5.0	86.0%
Carp fat	VN9640	0.7	2.3	ND	ND	ND	5.1	1.2	9.2	1.7	ND	ND	ND	1.5	46.7%
A So, Aluoi valley (Exposed)															
Former airbase soil (0-10 cm)	VN9642	110	120	7.8	13	47	460	3.6	11	8.8	8.4	28	36	112.6	97.7%
Former airbase soil (10-30 cm)	VN9622	32	34	0.2	7.8	23	430	1.1	2.7	2.9	3.7	6.7	7.5	33.3	96.1%
Fish pond sediment	VN9602	6.9	9.5	3.1	9.1	19	460	0.6	1.7	1.4	0.5	0.8	1.2	7.8	88.5%
A Sap River sediment	VN9650	0.8	0.8	ND	0.5	3.6	69	ND	0.4	ND	ND	ND	ND	1.2	66.7%
Carp fat	VN9646	51	59	2.4	ND	ND	ND	6.6	25	12	ND	ND	ND	53.7	95.0%
Carp liver	VN9614	2.4	3.0	0.4	ND	ND	ND	0.4	1.3	0.4	ND	ND	ND	2.6	92.3%
Duck liver	VN9608	1.4	1.4	ND	ND	ND	ND	0.2	0.2	ND	ND	ND	ND	1.6	87.5%
Dong Ha, Quang Tri province (Exposed)															
Former airbase soil (0-10 cm)	VN9645	ND	0.2	ND	9.2	58	290	0.4	1.1	3.5	11	23	26	1.6	0.0%
Former airbase soil (10-30 cm)	VN9630	ND	ND	ND	3.6	13	62	ND	ND	ND	1.3	2.1	3.9	0.6	0.0%
Chi Khe, Nhge An province (Reference)															
Farmer's field soil (0-10cm)	VN9636	ND	0.2	ND	1.8	1.3	13	0.2	1.1	0.1	0.8	ND	ND	0.4	0.0%
Farmer's field soil (10-30cm)	VN9624	ND	ND	ND	2.0	1.4	16	ND	0.8	ND	0.6	ND	ND	0.6	0.0%
Con Cuong, Nhge An province (Reference)															
Carp liver	VN9621	ND	0.1	ND	ND	ND	ND	0.2	0.4	0.3	ND	ND	ND	0.2	0.0%
Duck liver	VN9644	ND	ND	ND	ND	ND	ND	0.2	0.4	ND	ND	ND	ND	0.2	0.0%
Pig liver	VN9641	ND	ND	ND	ND	1.2	4.1	ND	ND	ND	ND	ND	ND	0.2	0.0%

ND = Not detected; for 'Total TEQ' calculations, if ND, ½ detection level was used.
NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

VN614: tbl4.3_96data4.XLS;7/3/98

Table 4.4 Concentrations of dioxin and furan congeners in soil, fishpond sediment, animal tissues and whole human blood, (pg/g dry weight [soils], pg/g wet weight [biological tissues]), central and southern Viet Nam, November 1997.

Sample Location and Type	Sample ID	Polychlorinated dioxin/furan congener concentration (pg/g) 2,3,7,8-T4CDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-T4CDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF	Total TEQ	% 2,3,7,8-T4CDD of TEQ
A So, Aluoi Valley, central Viet Nam (Exposed)															
Soil (0 to 10 cm)															
Manioc field	97VN001	6.61	8.26	1.56	8.49	10.92	142.29	0.64	3.17	0.87	0.55	0.92	1.61	7.01	94.3%
Ploughed field	97VN013	4.20	6.49	2.93	10.49	10.88	136.34	0.24	1.66	0.78	ND	0.78	1.95	4.53	92.7%
Former airbase	97VN051	897.85	897.85	7.76	24.35	68.44	563.84	10.46	30.30	23.59	8.19	19.83	16.50	901.22	99.6%
Former airstrip	97VN057	88.32	88.32	7.40	19.83	65.82	697.05	3.08	11.27	6.94	8.94	22.37	30.31	92.21	95.8%
Fish pond sediment															
Fish pond #1	97VN005	5.2	9.9	13	10	5.3	64	0.3	2.3	1.1	0.3	ND	ND	5.9	88.1%
Fish pond #2	97VN007	5.4	7.1	4.5	9.3	7.9	170	0.3	1.5	0.9	0.2	ND	ND	6.0	90.0%
Fish pond #3	97VN009	8.5	11	3.3	5.8	9.4	220	0.5	2.2	1.1	0.2	ND	ND	9.2	92.4%
Fish pond #4	97VN011	1.8	3.3	2.5	1.5	1.4	23	0.1	0.6	0.4	ND	ND	ND	2.0	90.0%
Animal tissue															
Grass carp fat (pond#1)	97VN019	7.9	10	2.3	1.5	1.6	2.9	2.3	13	3.4	0.5	0.4	NDR	8.7	90.8%
Grass carp fat (pond#2)	97VN027	16	20	4.2	1.4	0.7	1.0	2.4	11	4.0	1.1	0.1	ND	16.7	95.8%
Grass carp fat (pond#3)	97VN031	21	25	4.0	0.6	0.8	3.3	4.0	15	5.0	ND	0.5	ND	22.4	93.8%
Grass carp fat (pond#4)	97VN039	34	41	9.5	1.8	0.2	0.6	4.4	15	5.3	0.6	0.2	0.1	35.4	96.0%
Duck fat	97VN045	6.1	7.0	3.4	0.8	ND	2.2	1.1	2.7	2.1	ND	ND	ND	7.0	87.1%
Human blood (lipid basis)															
Males, age >25	97VN047	31	31	ND	6.9	10	52	ND	ND	3.4	17	ND	NDR	37.2	83.4%
Females, age >25	97VN048	11	11	ND	ND	14	64	ND	ND	ND	ND	ND	NDR	14.3	76.9%
Males, age 12 to 25	97VN049	21	21	ND	ND	10	NDR	ND	ND	ND	14	24	76	25.5	82.4%
Females, age 12 to 25	97VN050	12	12	ND	ND	19	50	ND	ND	ND	ND	12	ND	15.4	78.0%
Rang Rang, Ma Da forest region, southern Viet Nam (Exposed)															
Soil (0 to 10 cm)															
South of former airstrip	97VN075	7.86	10.13	1.41	7.22	6.62	16.58	1.03	4.02	1.54	0.51	ND	0.81	8.44	93.1%
North of Ma Da River	97VN077	19.10	24.88	8.94	26.37	7.54	26.86	2.48	8.98	5.42	1.13	1.44	1.40	20.33	93.9%
At former airstrip	97VN079	1.82	2.46	3.76	7.60	9.58	24.91	0.59	1.15	0.71	ND	1.07	ND	2.37	76.8%
Sediment															
Fish pond near Ba Hao	97VN073	7.80	9.71	ND	ND	5.85	29.51	0.59	0.88	1.07	ND	1.32	1.41	7.93	98.4%
Ba Hao Reservoir	97VN089	2.28	3.34	ND	7.59	10.40	18.76	0.27	2.12	ND	ND	1.01	0.69	2.64	86.4%

ND = Not detected; for 'Total TEQ' calculations, if ND, ½ detection level was used.

NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

Table 4.5 **Pesticide residues (ng/g dry weight [soils]; wet weight [biological tissues]) in samples collected from Viet Nam, January 1996 and November 1997 (in italics). Values in parentheses represent levels on a lipid basis.**

District	Commune	Sample ID # Vietnam	HCL	Site Type	Sample Type	% Lipid	Hexachloro-benzene	alpha HCH	beta HCH	gamma HCH	Hepta-chlor	Aldrin	Oxy-chlordane	trans-Chlordane	cis-Chlordane	o,p'-DDE	p,p'-DDE	trans-Nonachlor
Aluoi	Son Thuy	VN9629	125	exposed	pig liver	3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5 (50)	ND
Aluoi	A So	VN9642	171	exposed	former airbase soil (0-10cm)	n/a	0.03	ND	ND	ND	ND	ND	ND	0.006	0.007	0.25	36	0.008
Aluoi	A So	VN9622	173	exposed	former airbase soil (10-30cm)	n/a	0.18	ND	ND	ND	ND	ND	ND	ND	ND	0.05	11	ND
Aluoi	A So	VN9646	198	exposed	carp fat	87.0	3.2 (4)	11 (13)	3.4 (4)	2.7 (3)	ND	ND	ND	ND	ND	9.3 (11)	450 (517)	0.38 (0.4)
Aluoi	*A So*	-	*97VN003*	*exposed*	*manioc field soil (10-30cm)*	*n/a*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Aluoi	*A So*	-	*97VN015*	*exposed*	*ploughed sweet potato field (10-30cm)*	*n/a*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*2.0*	*ND*
Dong Ha	Dong Ha	VN9645	277	exposed	former airbase soil (0-10cm)	n/a	0.03	0.02	0.05	ND	ND	ND	0.02	0.47	0.47	0.02	0.31	0.44
Dong Ha	Dong Ha	VN9630	279	exposed	former airbase soil (10-30cm)	n/a	0.04	ND	ND	ND	ND	ND	0.01	0.1	0.09	ND	0.08	0.05
Con Cuong	Chi Khe	VN9636	320	reference	farmer's field soil (0-10cm)	n/a	7.8	ND	ND	ND	ND	ND	ND	ND	ND	60	2500	ND
Con Cuong	Chi Khe	VN9624	322	reference	farmer's field soil (10-30cm)	n/a	8.4	ND	ND	ND	ND	ND	ND	ND	ND	62	2300	ND
Con Cuong	Con Cuong	VN9641	300	reference	pig liver	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.76 (23)	ND

Table 4.5 **cont'd.**

District	Commune	Sample ID # Vietnam	HCL	Site Type	Sample Type	% Lipid	cis-Nonachlor	o,p'-DDD	p,p'-DDD	o,p'-DDT	p,p'-DDT	Mirex	Heptachlor Epoxide	alpha-Endosulphan (I)	Dieldrin	Endrin	Methoxy-chlor
Aluoi	Son Thuy	VN9629	125	exposed	pig liver	3.0	ND	ND	0.92 (31)	ND	ND	ND	ND	ND	ND	ND	ND
Aluoi	A So	VN9642	171	exposed	former airbase soil (0-10cm)	n/a	0.004	1.9	16	2.2	18	ND	ND	ND	ND	ND	ND
Aluoi	A So	VN9622	173	exposed	former airbase soil (10-30cm)	n/a	ND	0.46	5.9	1.0	24	ND	ND	ND	ND	ND	ND
Aluoi	A So	VN9646	198	exposed	carp fat	87	ND	79 (90)	500 (574)	43 (49)	13 (15)	ND	0.27 (0.31)	3.1 (4)	0.83 (0.95)	ND	ND
Aluoi	*A So*	-	*97VN003*	*exposed*	*manioc field soil (10-30cm)*	*n/a*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Aluoi	*A So*	-	*97VN015*	*exposed*	*ploughed sweet potato field (10-30cm)*	*n/a*	*NDR*	*1.1*	*0.41*	*1.0*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
Dong Ha	Dong Ha	VN9645	277	exposed	former airbase soil (0-10cm)	n/a	0.26	0.31	0.84	0.04	0.21	ND	ND	ND	ND	ND	ND
Dong Ha	Dong Ha	VN9630	279	exposed	former airbase soil (10-30cm)	n/a	0.05	0.07	0.2	0.03	0.36	ND	ND	ND	ND	ND	ND
Con Cuong	Chi Khe	VN9636	320	reference	farmer's field soil (0-10cm)	n/a	ND	290	1700	1200	11000	ND	ND	ND	ND	ND	ND
Con Cuong	Chi Khe	VN9624	322	reference	farmer's field soil (10-30cm)	n/a	ND	320	1900	1100	15000	ND	ND	ND	ND	ND	ND
Con Cuong	Con Cuong	VN9641	300	reference	pig liver	3.3	ND	ND	0.4 (12)	ND	ND	ND	ND	ND	ND	ND	ND

ND = Not detected.
NDR = Peak detected but did not meet quantification criteria.

Table 4.6 **Herbicide residues (ng/g dry weight) in samples collected from Viet Nam, January 1996.**

District	Commune	Sample ID # Vietnam	HCL	Site Type	Sample Type	2,4-Dichlorophenoxy Acetic Acid	Dicamba	2,4-DB	Dichlor-prop	Dinoseb	MCPA	Picloram	Silvex (2,4,5-TP)	2,4,5-T
Aluoi	A So	VN9642	171	exposed	former airbase soil (0-10cm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.50	<0.01	<0.01	<0.01
Aluoi	A So	VN9622	173	exposed	former airbase soil (10-30cm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.50	<0.01	<0.01	<0.01
Dong Ha	Dong Ha	VN9645	277	exposed	former airbase soil (0-10cm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.50	<0.01	<0.01	<0.01
Dong Ha	Dong Ha	VN9630	279	exposed	former airbase soil (10-30cm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.50	<0.01	<0.01	<0.01
Con Cuong	Chi Khe	VN9636	320	reference	farmer's field soil (0-10cm)	<0.01	<0.01	<0.01	<0.01	<0.02	<0.50	<0.01	<0.01	<0.01
Con Cuong	Chi Khe	VN9624	322	reference	farmer's field soil (10-30cm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.50	<0.01	<0.01	<0.01

Table 4.7 PCB residues (ng/g dry weight [soils]; wet weight [biological tissues]) in samples collected from central Viet Nam, January 1996 and November 1997 (in italics).

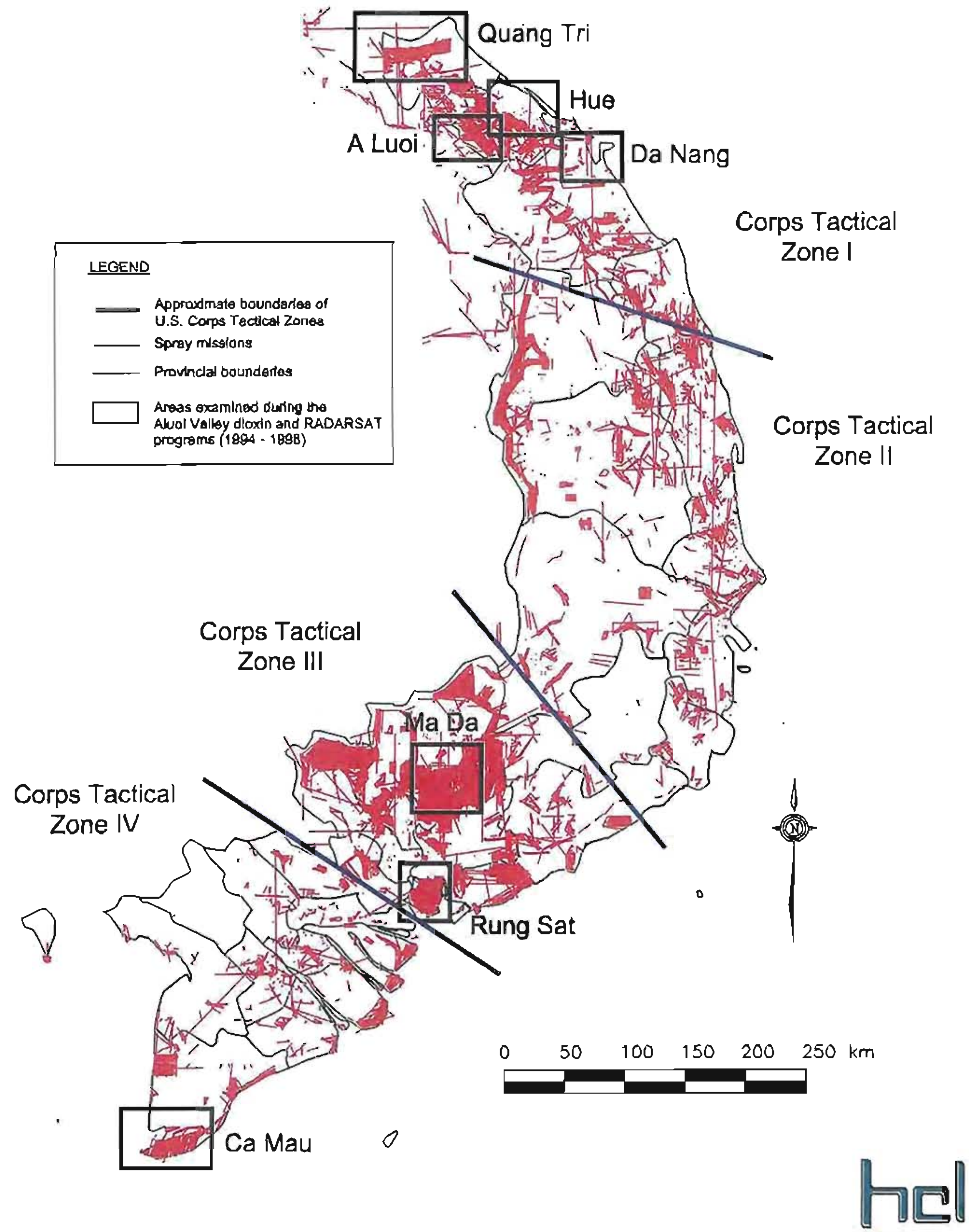
District	Commune	Sample ID # Vietnam	Sample ID # HCL	Site Type	Sample Type	Aroclor 1242	Aroclor 1254	Aroclor 1260
Aluoi	Son Thuy	VN9629	125	exposed	pig liver	ND	ND	ND
Aluoi	A So	VN9642	171	exposed	former airbase soil (0-10cm)	ND	0.37	0.42
Aluoi	A So	VN9622	173	exposed	former airbase soil (10-30cm)	ND	ND	2.5
Aluoi	A So	VN9646	198	exposed	carp fat (Pond #1)	ND	ND	ND
Aluoi	*A So*	-	*97VN003*	*exposed*	*manioc field soil (10-30cm)*	*ND*	*ND*	*ND*
Aluoi	*A So*	-	*97VN015*	*exposed*	*ploughed sweet potato field (10-30cm)*	*ND*	*ND*	*ND*
Dong Ha	Dong Ha	VN9645	277	exposed	former airbase soil (0-10cm)	ND	0.4	0.66
Dong Ha	Dong Ha	VN9630	279	exposed	former airbase soil (10-30cm)	ND	0.13	0.53
Con Cuong	Chi Khe	VN9636	320	reference	farmer's field soil (0-10cm)	ND	ND	ND
Con Cuong	Chi Khe	VN9624	322	reference	farmer's field soil (10-30cm)	ND	ND	ND
Con Cuong	Con Cuong	VN9641	300	reference	pig liver	ND	ND	ND

ND = Not detected.

NDR = Peak detected but did not meet quantification criteria.

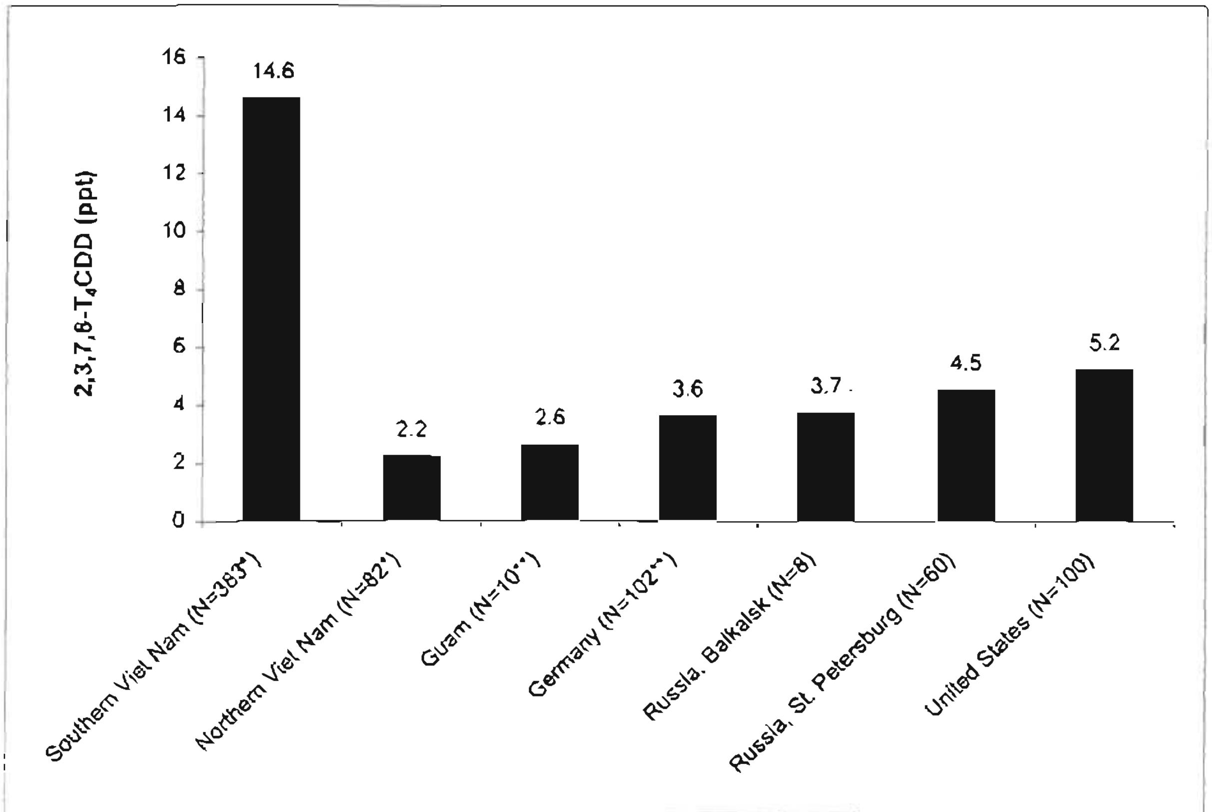
Figures

Figure 1.1 Aerial herbicide spray missions in southern Viet Nam, 1965 to 1971 (Source: U.S. Dept. of the Army).



VN614: HERB_9.DWG

Figure 3.1 2,3,7,8-T4CDD (ppt, lipid basis) in human blood from different countries; data from Schecter *et al.* (1992b).

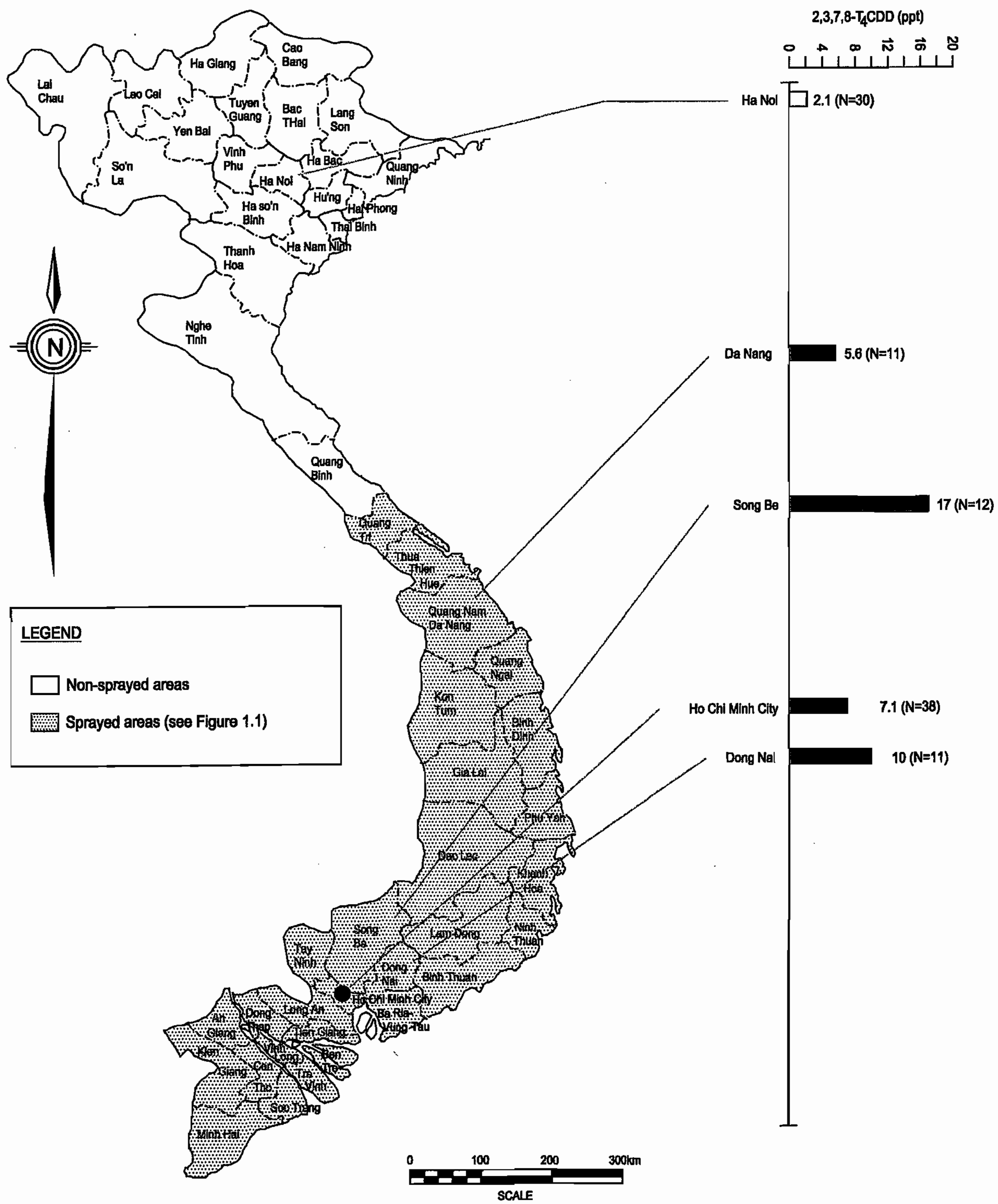


* Northern and Southern Viet Nam are means of several pooled analyses. Northern is from two analyses with a total of 82 persons; Southern is from nine analyses totalling 383 persons.

** German and Guam data are means from individual analyses; all others are from pooled blood.

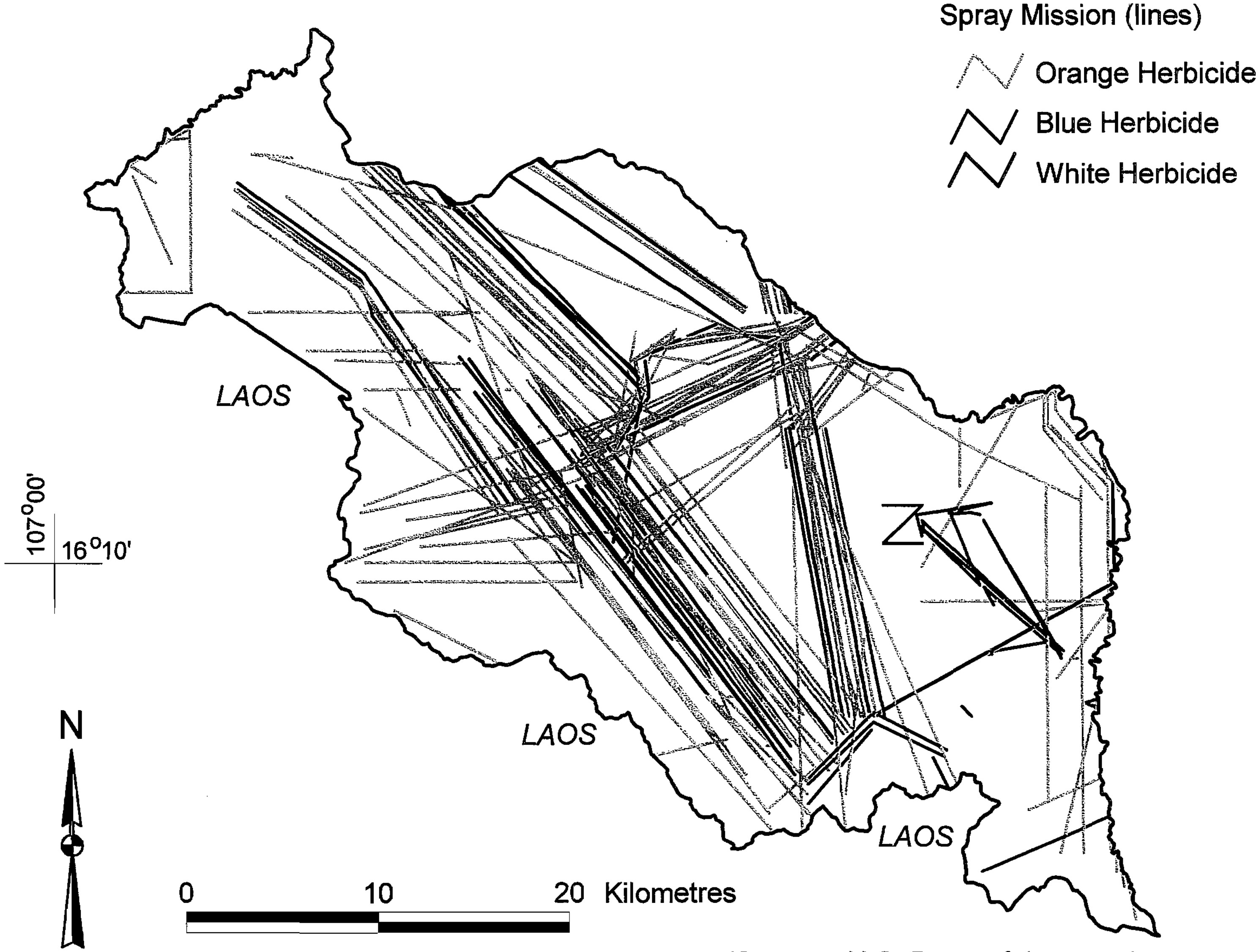
N = sample size.

Figure 3.2 2,3,7,8-T4CDD (ppt, lipid basis) in pooled human breast milk from different localities of Viet Nam in 1985 to 1990 (Source: Schecter 1994b).



VN614: MILK_7.DWG

Figure 4.1 Herbicide spray missions, Aluoi Valley, Viet Nam (1965-1970).

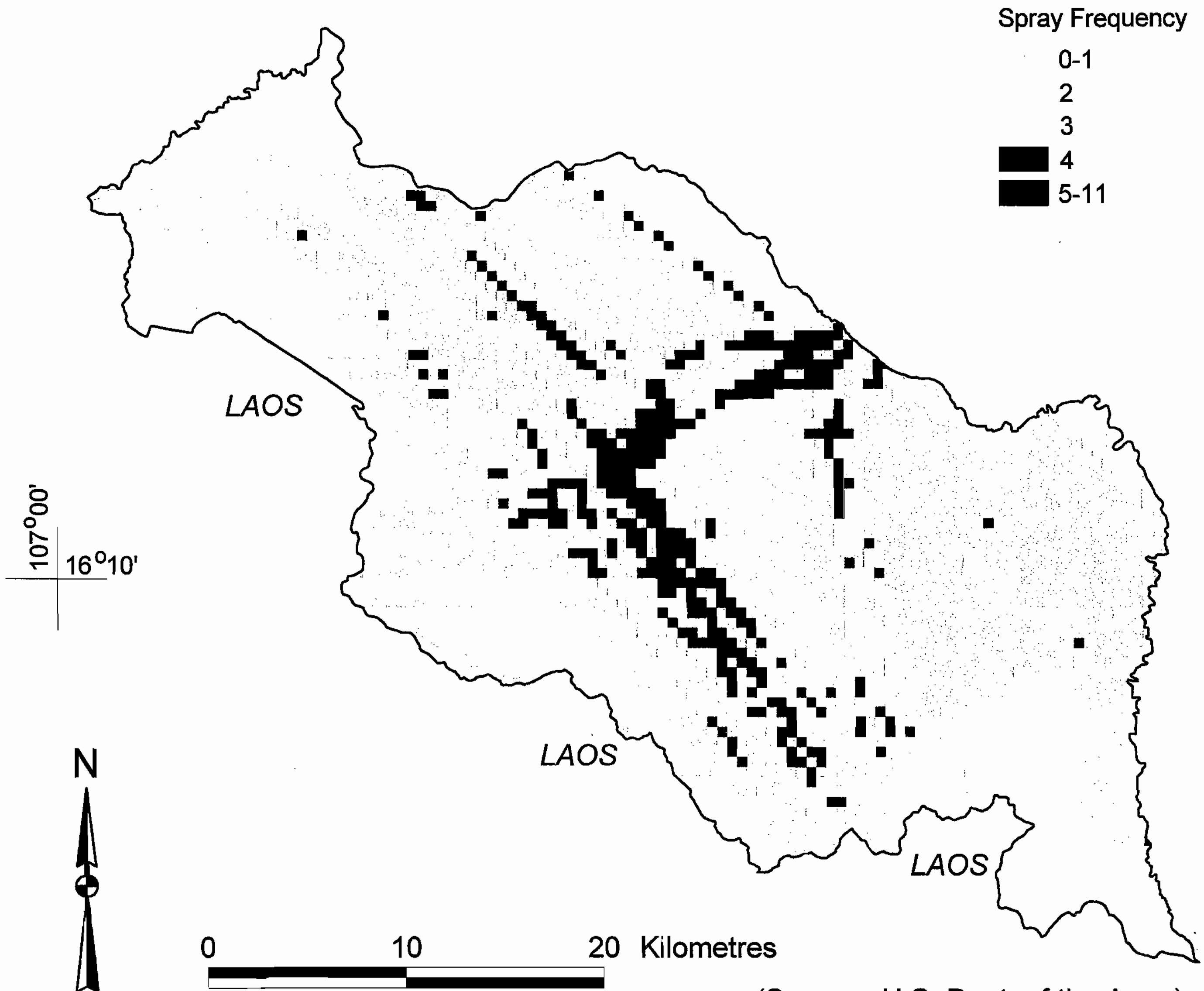


(Source: U.S. Dept. of the Army)

hcl

VN614: SPRLBND1_NEW11.APR

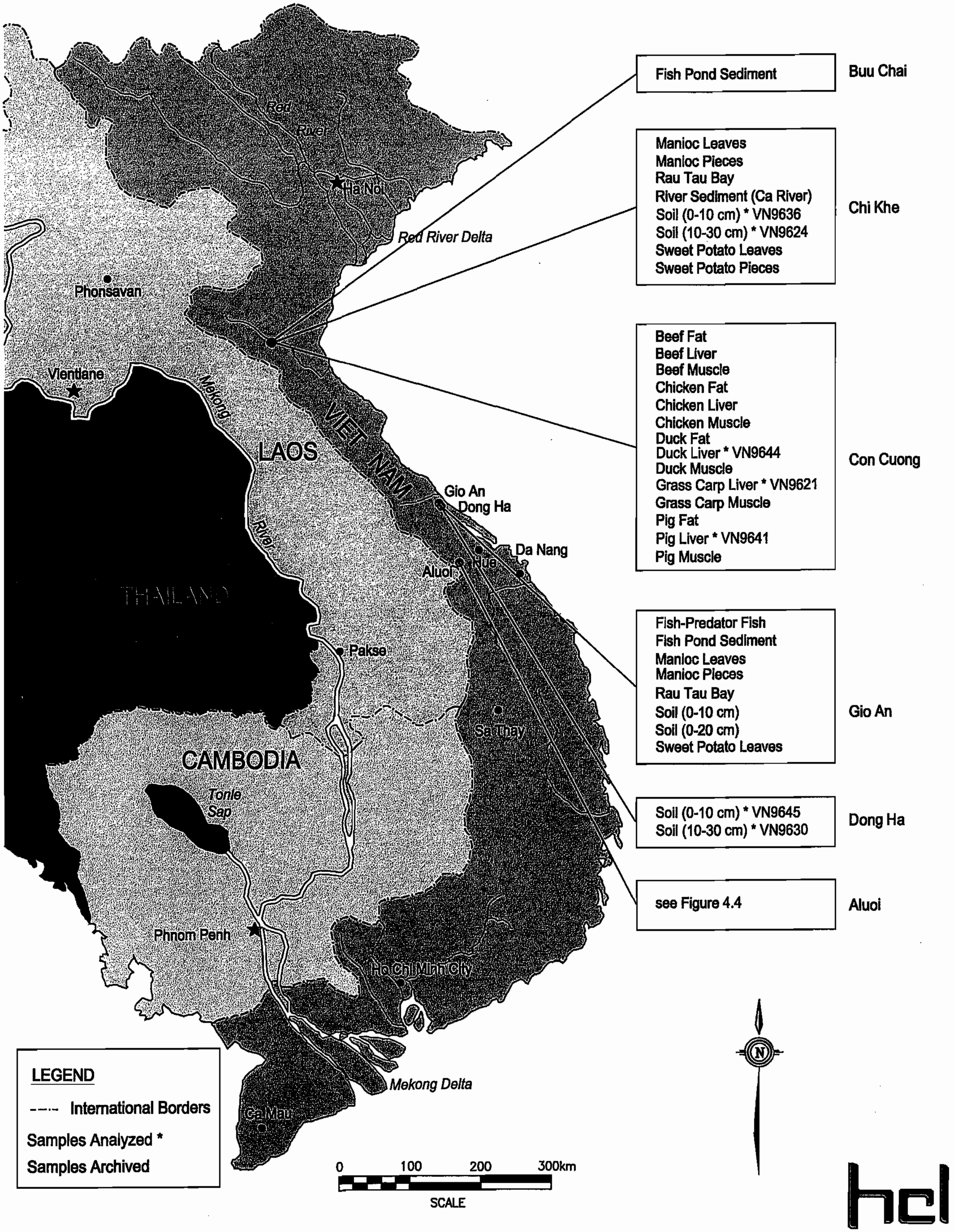
Figure 4.2 Aluoi Valley, Viet Nam, herbicide distribution/frequency of spray missions (1965-1970).



(Source: U.S. Dept. of the Army)

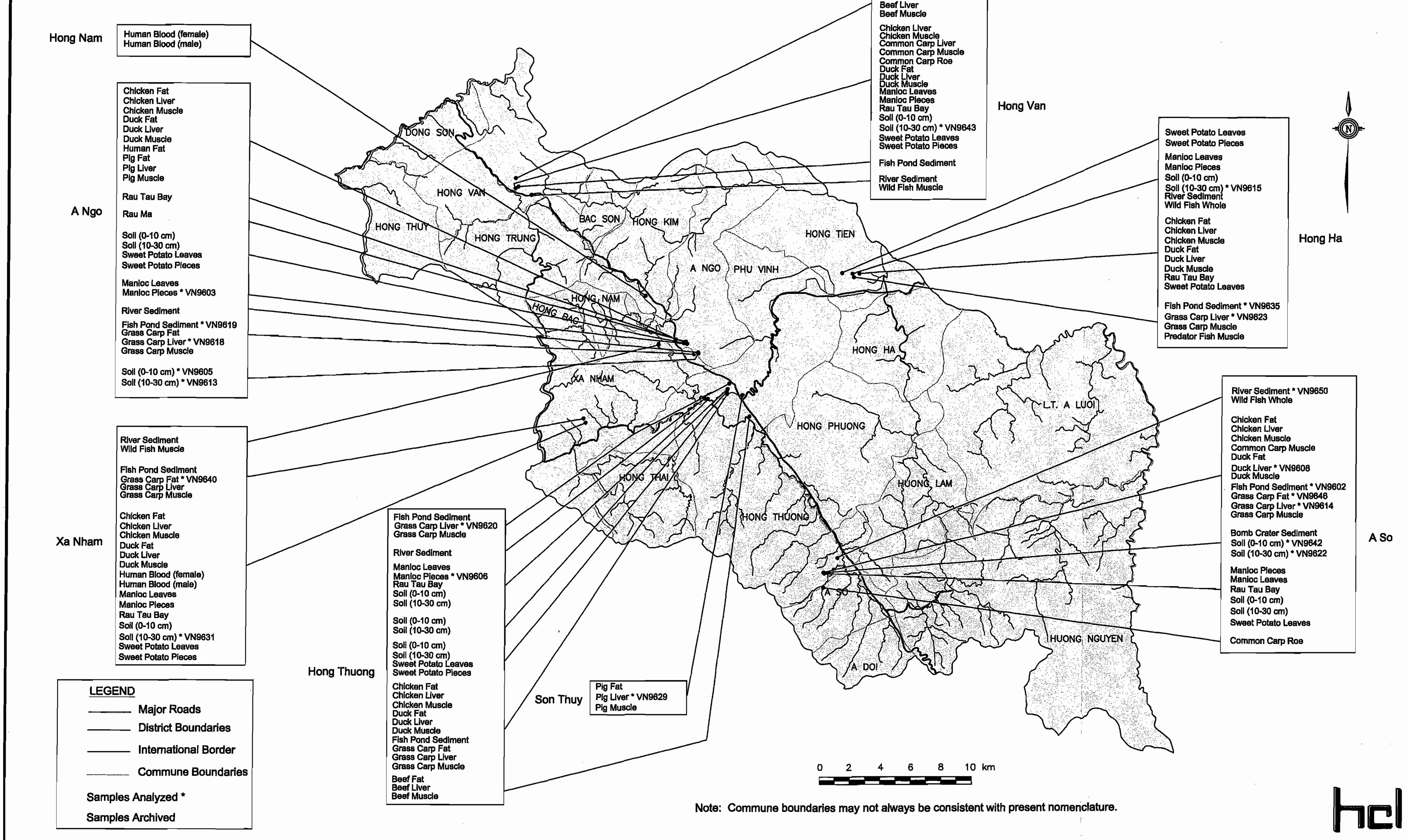
VN614: SPRLDIS1_NEW11.APR

Figure 4.3 Sampling locations, Viet Nam, 1996 (Hatfield Consultants Ltd. and 10-80 Committee).



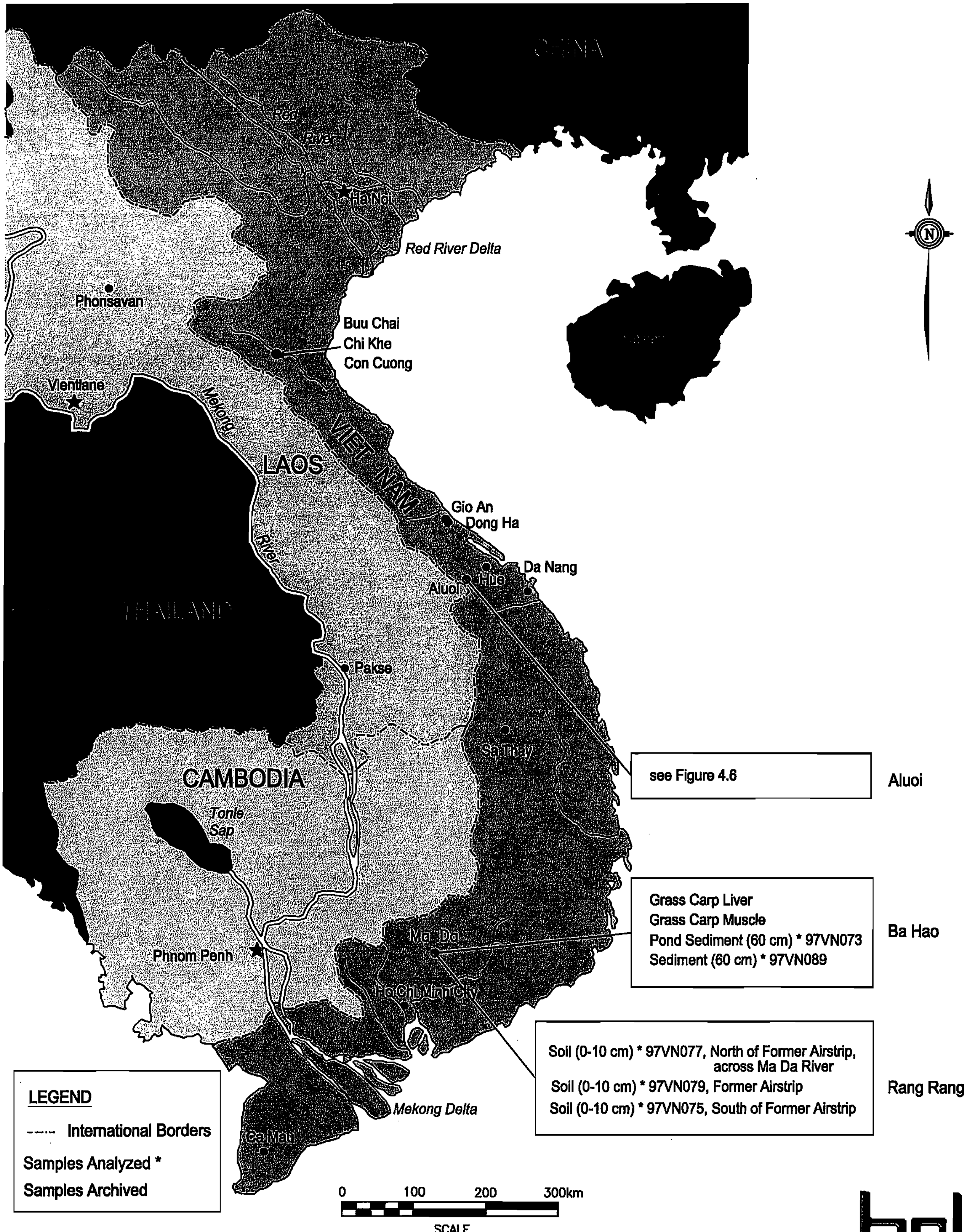
VN614: 96CONT_11.DWG

Figure 4.4 Aluoi Valley, Viet Nam, sampling locations, 1996 (Hatfield Consultants Ltd. and 10-80 Committee).



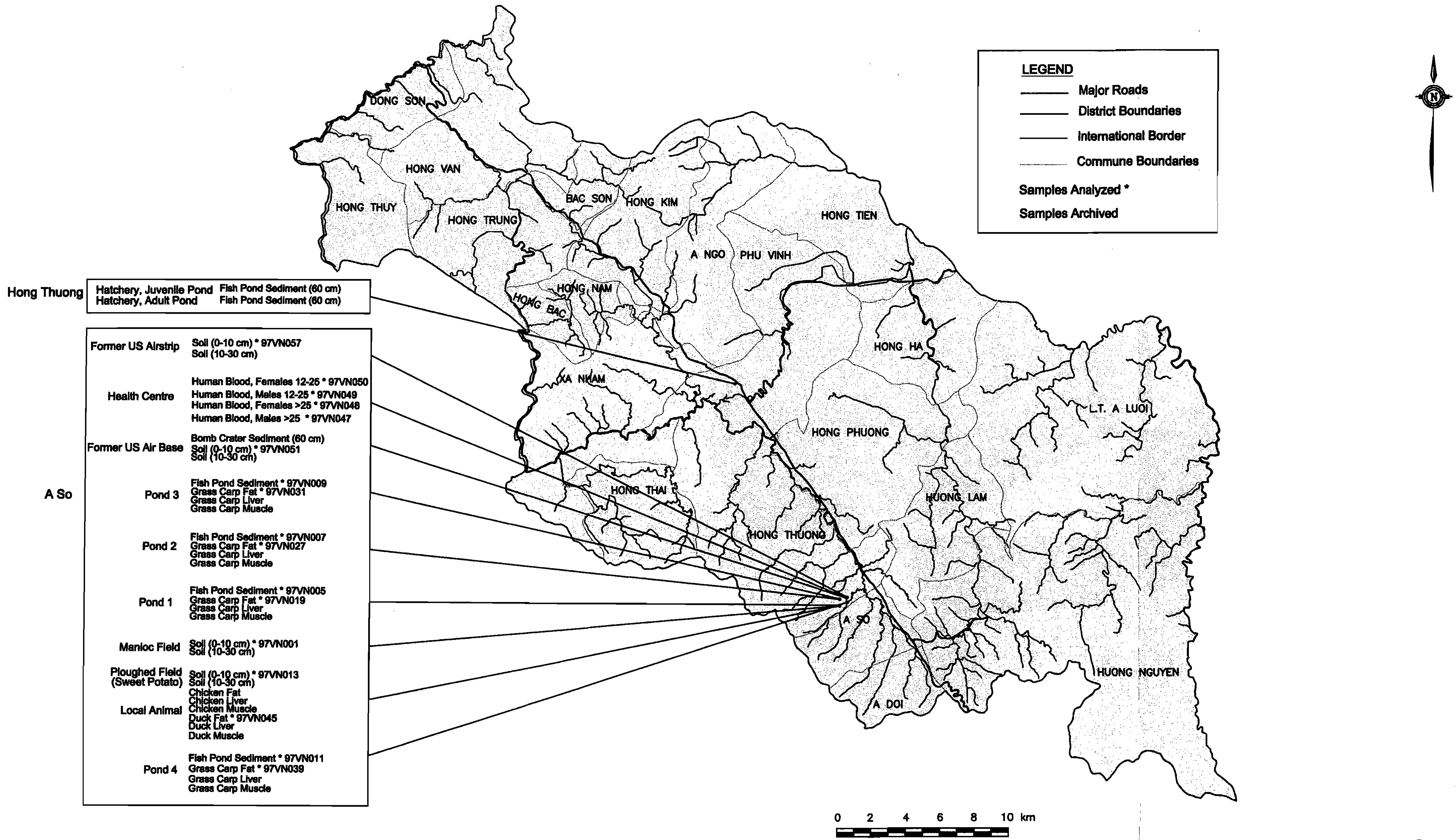
VN614: 96ALUOI_8.DWG

Figure 4.5 Sampling locations, Viet Nam, 1997 (Hatfield Consultants Ltd. and 10-80 Committee).



VN614: 97MA_DA_10.DWG

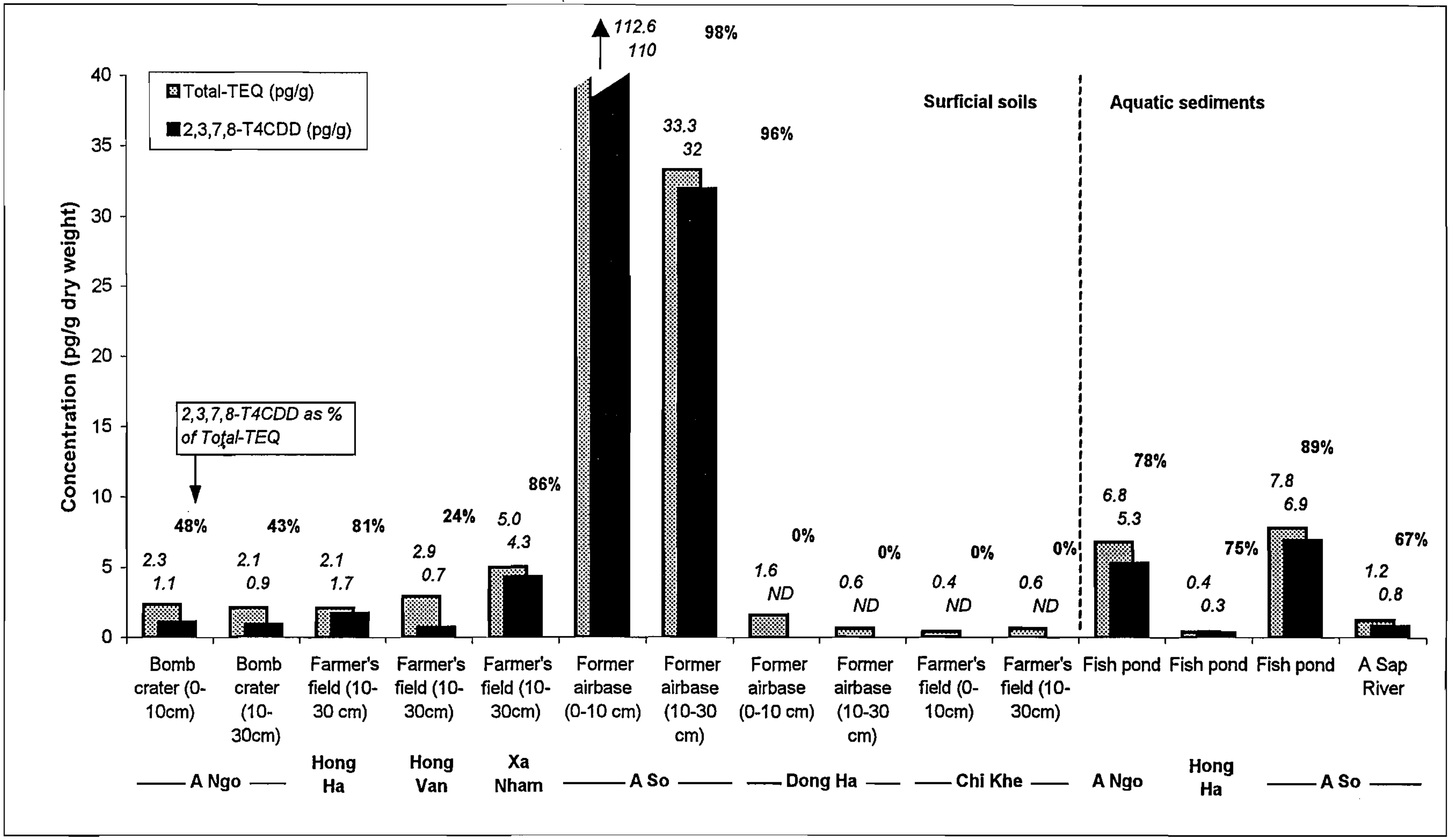
Figure 4.6 Aluoi Valley, Viet Nam, sampling locations, 1997 (Hatfield Consultants Ltd. and 10-80 Committee).



Note: Commune boundaries may not always be consistent with present nomenclature.

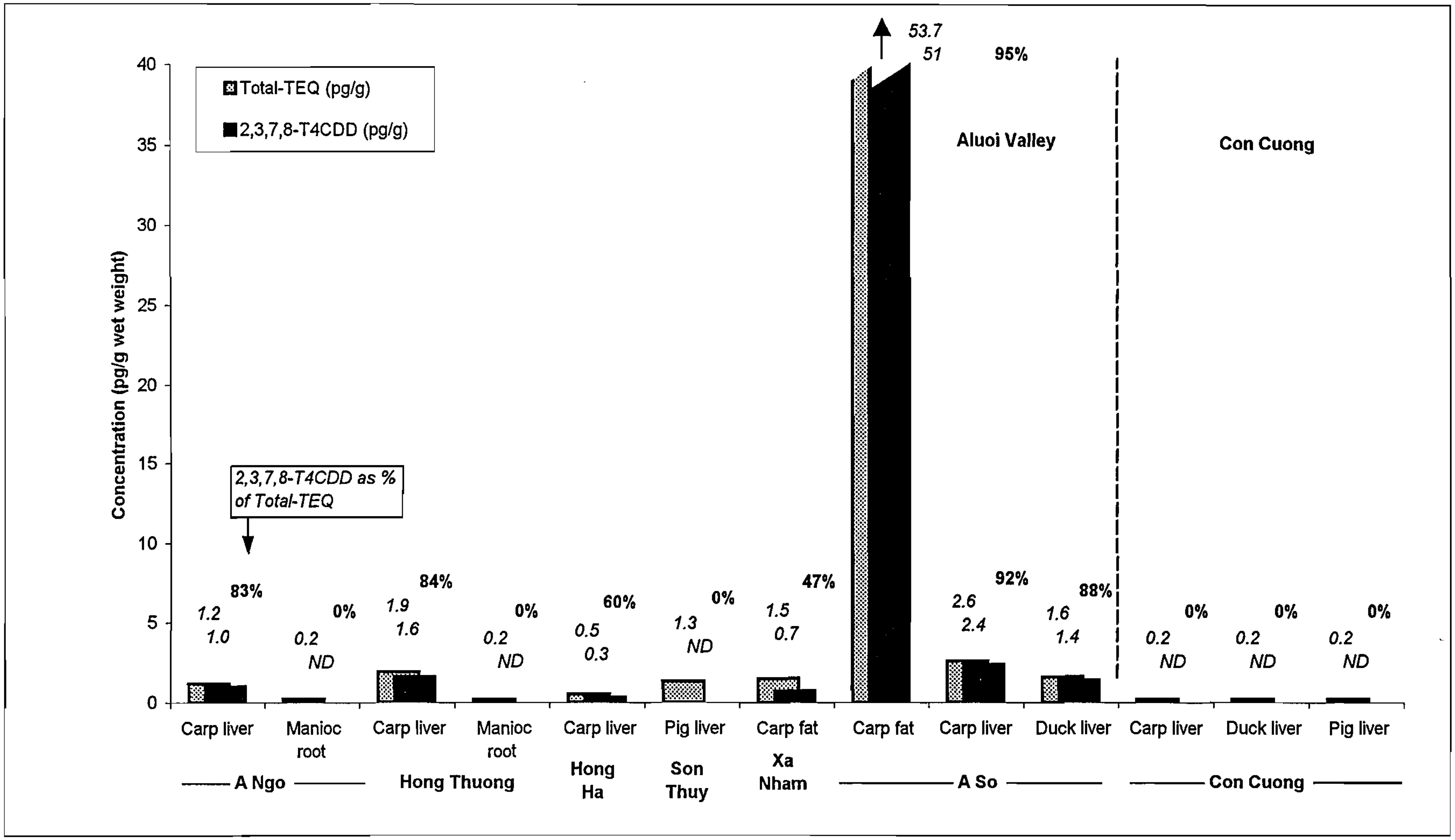
VN614: 97ALUOI_7.DWG

Figure 4.7 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in surficial soils and aquatic sediments collected from various locations in central Viet Nam, January 1996.



ND = not detected

Figure 4.8 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in biological tissues collected from Aluoi Valley (exposed sites) and Con Cuong (reference sites), Viet Nam, January 1996.



ND = not detected

Figure 4.9 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in fishpond sediments (pg/g dry weight) and biological tissues (pg/g wet weight), A So, Aluoi Valley, central Viet Nam, November 1997.

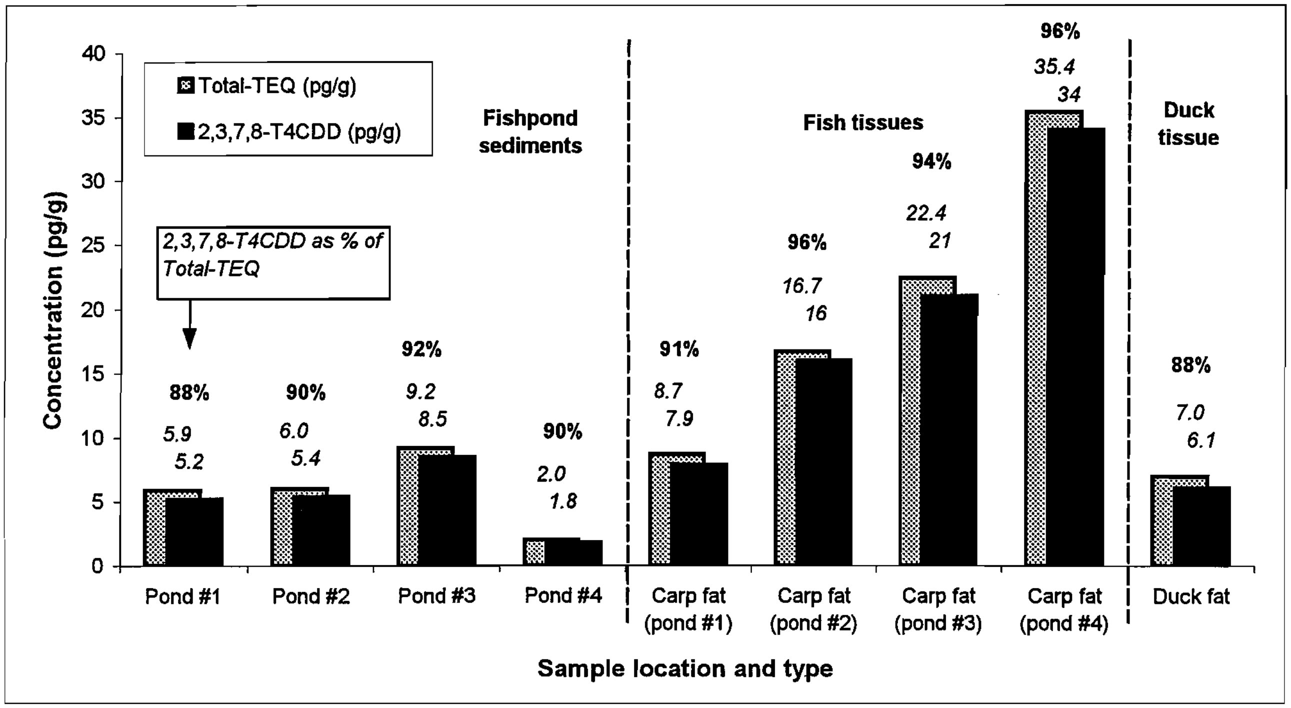


Figure 4.10 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in surficial soils, A So, Aluoi Valley, central Viet Nam, November 1997.

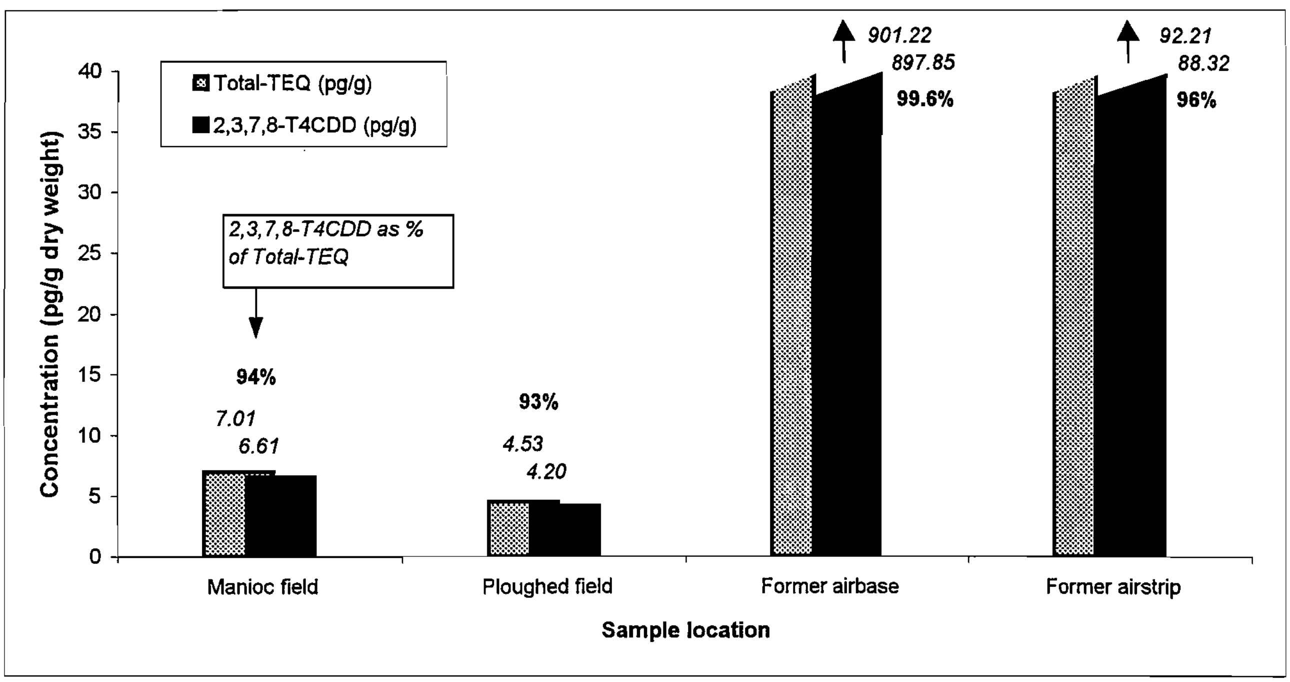


Figure 4.11 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in aquatic sediments and soil, Ma Da forest region, southern Viet Nam, November 1997.

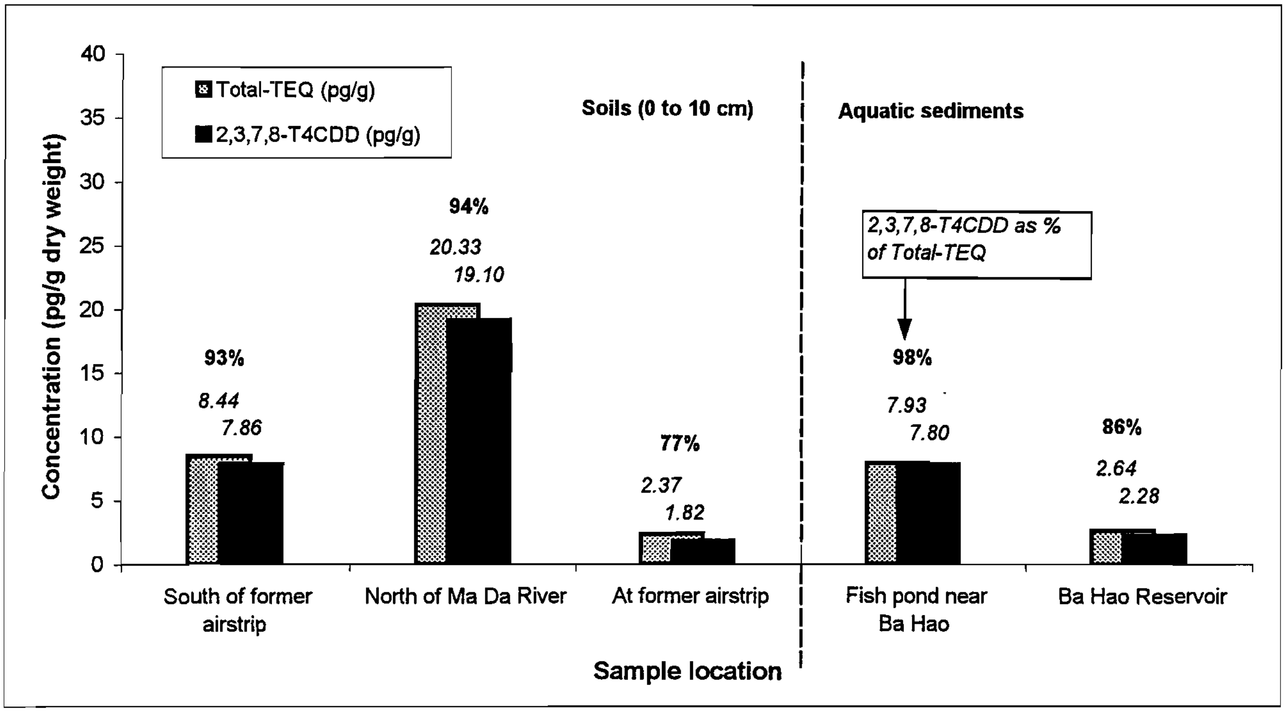
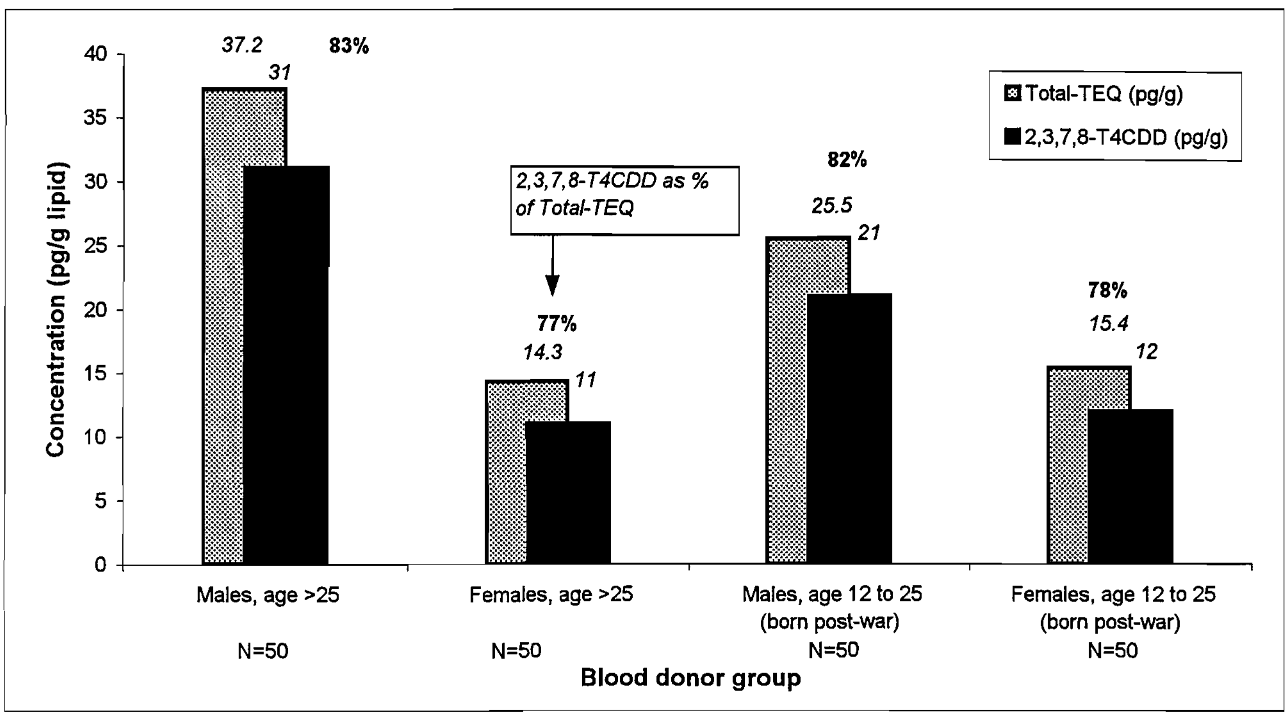
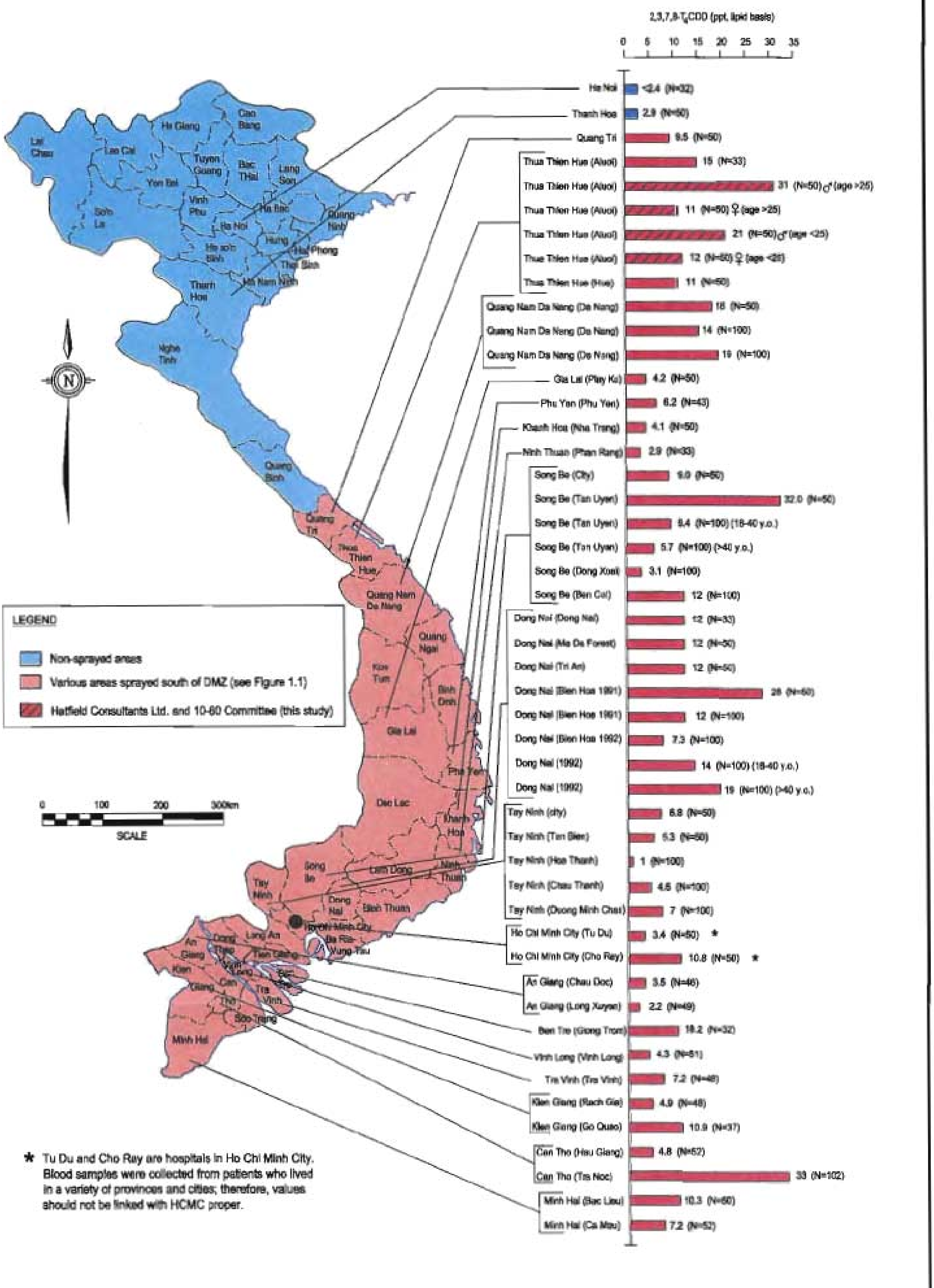


Figure 4.12 Concentrations of 2,3,7,8-T4CDD and Total-TEQ in whole human blood (lipid portion), A So, Aluoi Valley, central Viet Nam, November 1997.



hcl

Figure 4.13 2,3,7,8-T4CDD (ppt, lipid basis) in pooled blood from different localities of Viet Nam, 1987 to 1992 (Dai *et al.* 1994a, 1995; Schecter 1992a, 1994b) and 1997 (this study).

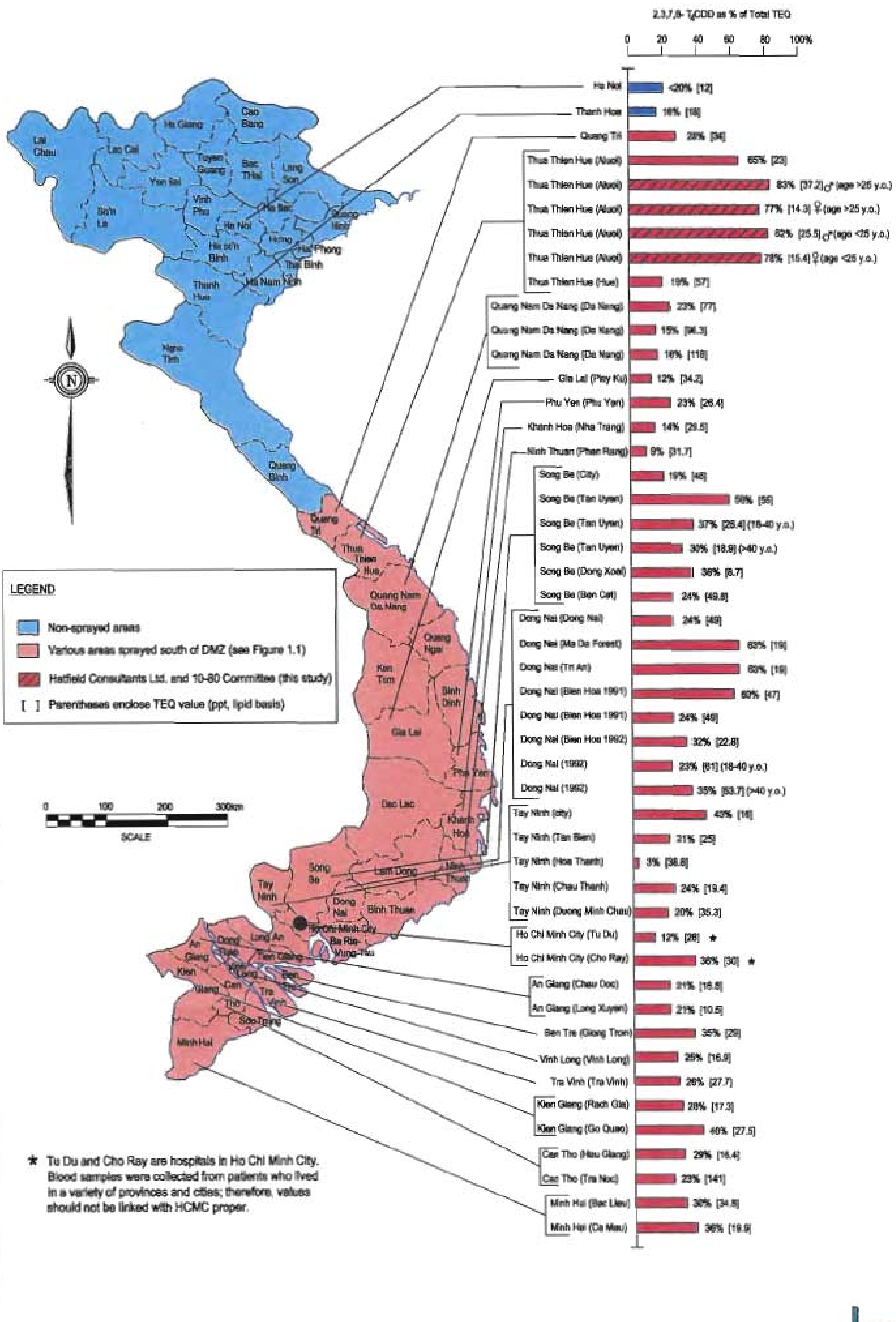


* Tu Du and Cho Ray are hospitals in Ho Chi Minh City. Blood samples were collected from patients who lived in a variety of provinces and cities; therefore, values should not be linked with HCMC proper.

hcl

VN814: DAL_15todd.DWG

Figure 4.14 2,3,7,8-T4CDD as % of Total TEQ in pooled blood from different localities of Viet Nam, 1987 to 1992 (Dai *et al.* 1994a, 1995; Schecter 1992a, 1994b) and 1997 (this study).



★ Tu Du and Cho Ray are hospitals in Ho Chi Minh City. Blood samples were collected from patients who lived in a variety of provinces and cities; therefore, values should not be linked with HCMC proper.

hcl

VN614: DAI_15TEQ.DWG

Plates

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Plate 1.1: Section of Aluoi Valley, looking west to Laos, approximately 5 km south of the main valley road junction which runs east to Hue (cf. Figure 4.4). The area shown above consisted primarily of natural forest prior to the Viet Nam war. Presently, vegetation in this region consists of low-grade trees, vines, bushes, bamboo and grasses.

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Plate 1.2: Section of Aluoi Valley, looking northeast up the valley, from a position at the extreme right on Plate 1.1. Note the denuded slopes and scrub vegetation in the valley.

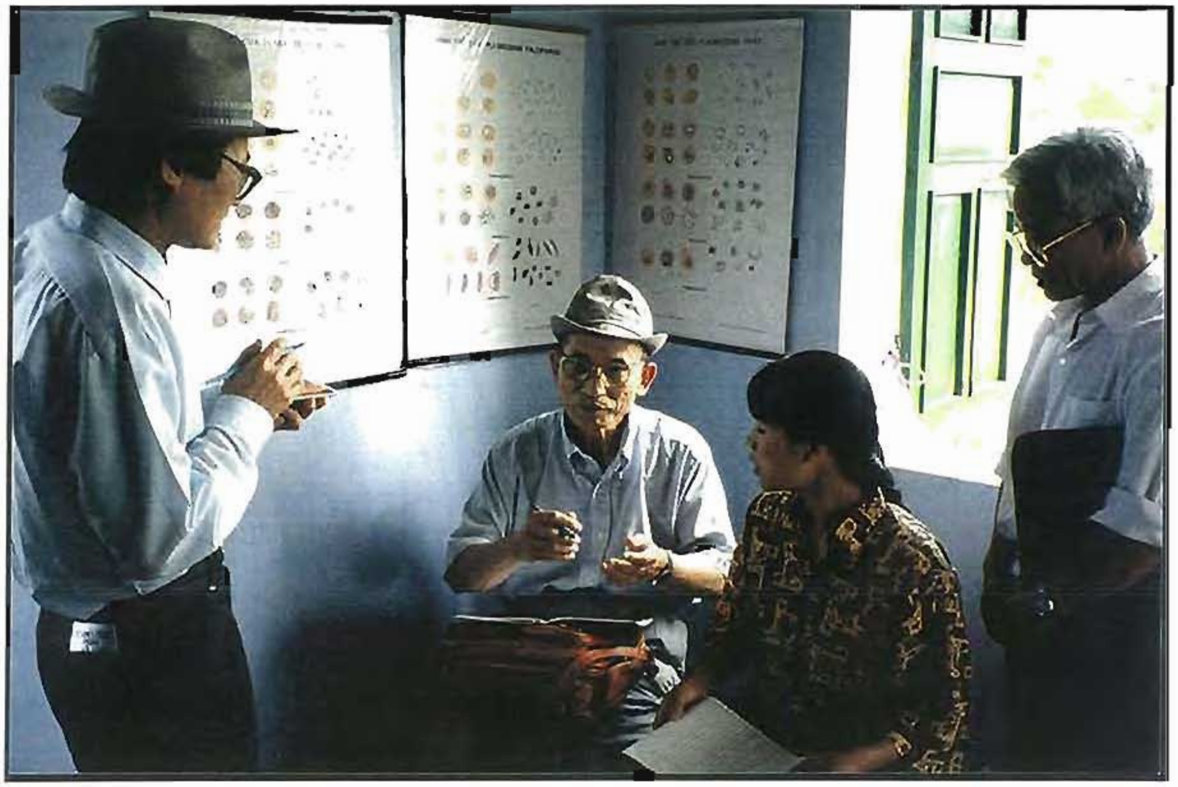

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Plate 2.1: Meeting with Aluoi Health Department personnel to discuss the proposed sampling program, 1995.

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Plate 2.2: Workshop held with 10-80 Committee to discuss sampling protocols, 1995.

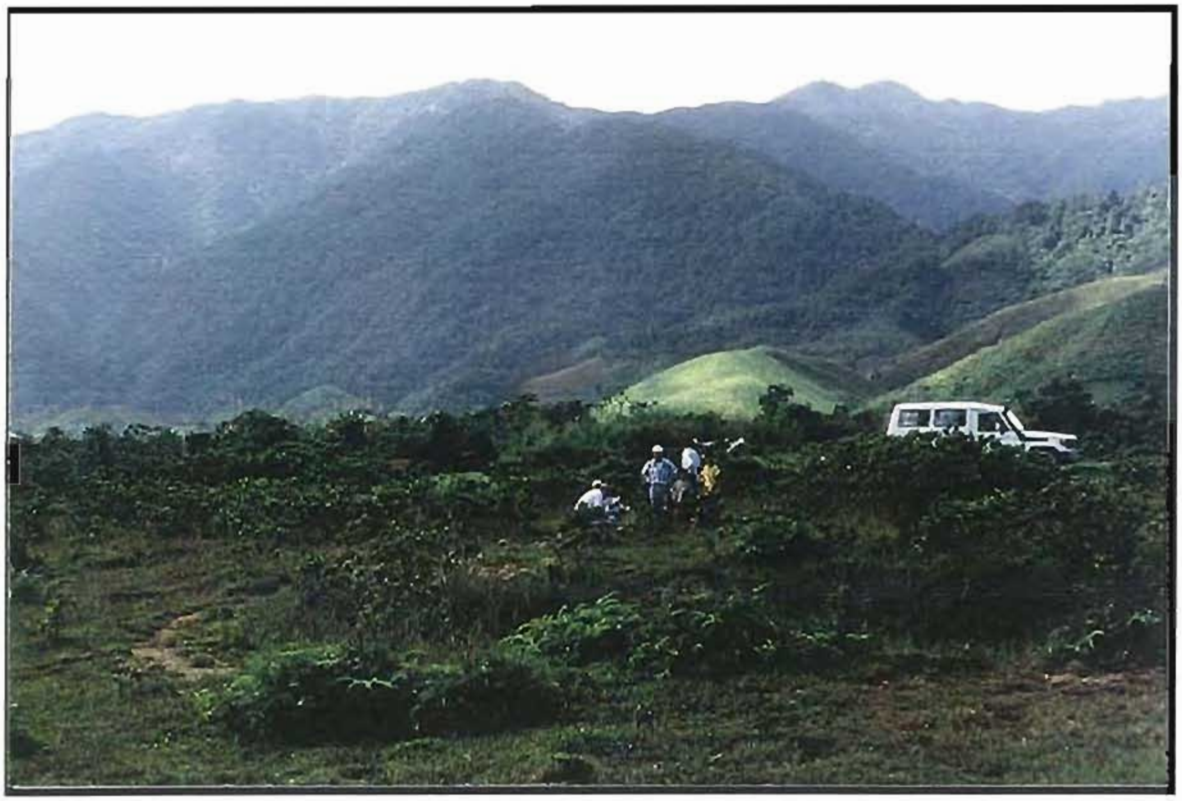

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Plate 2.3: Near the airstrip of the former airbase at A So (looking west to Laos).

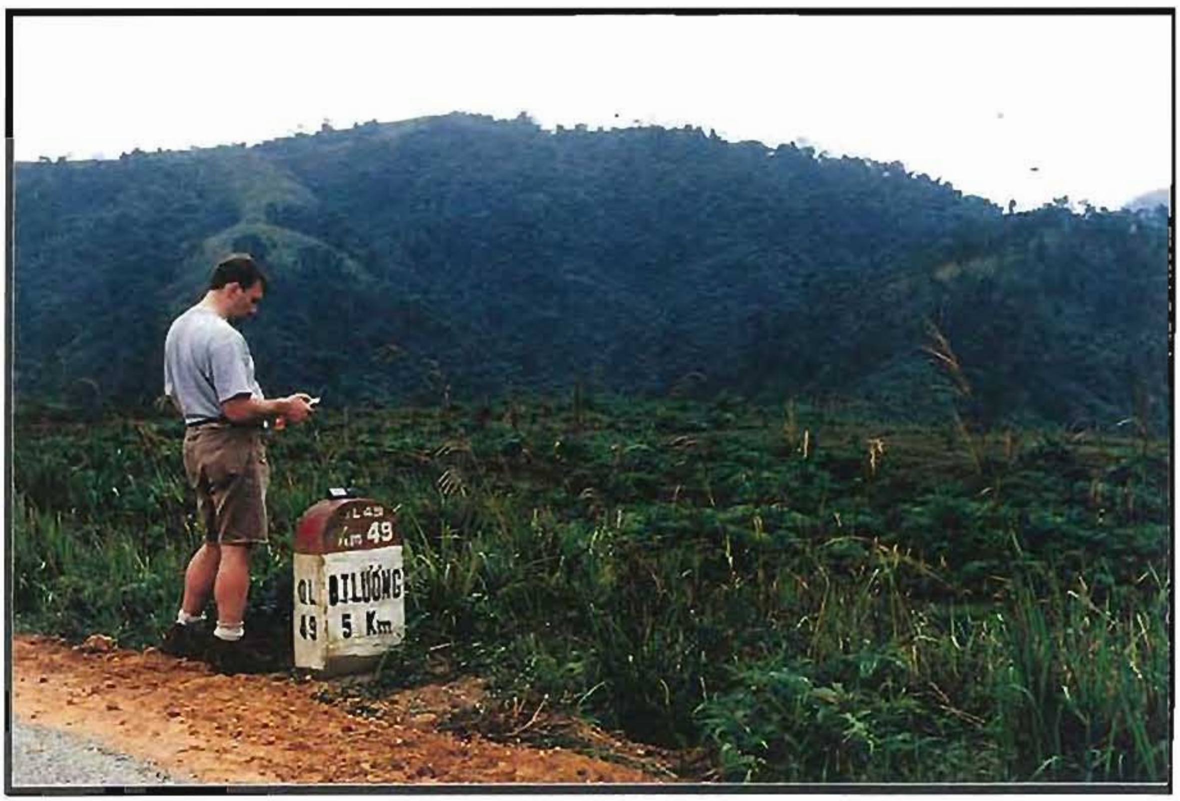

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Plate 2.4: Recording site sampling locations using Global Positioning System (GPS).

Plate 3.1: Aerial view of mangrove forests in the Rung Sat area of southern Viet Nam; the area pictured did not receive herbicide applications during the war (1969 photo courtesy of Dr. E.W. Pfeiffer).

Plate 3.2: Aerial view of mangrove forests in the Rung Sat area of southern Viet Nam subsequent to herbicide applications (photo taken in 1969; herbicide applications occurred in the early to mid 1960s [*pers. comm.* Dr. E.W. Pfeiffer]; photo courtesy of Dr. E.W. Pfeiffer).

E.W. Pfeiffer

Plate 3.3: Mangrove (Rung Sat area) in southern Viet Nam subsequent to herbicide applications (photo taken in 1969; herbicide applications occurred in the early to mid 1960s; *pers. comm.* Dr. E.W. Pfeiffer).

hcl

E.W. Pfeiffer

Plate 3.4: Mangrove (Rung Sat area) in southern Viet Nam subsequent to herbicide applications (photo taken in 1969; herbicide applications occurred in the early to mid 1960s; *pers. comm.* Dr. E.W. Pfeiffer).

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Plate 4.1: A So village, Aluoi Valley, looking east towards Hue.

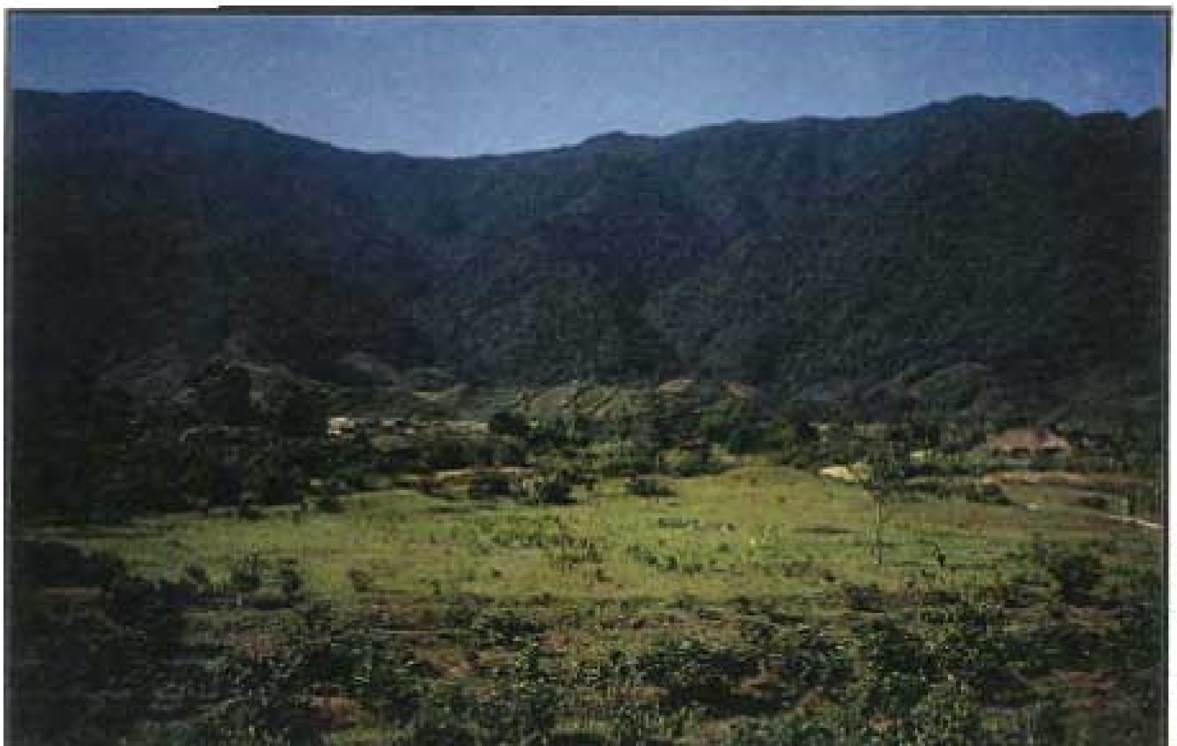

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Plate 4.2: A So village, Aluoi Valley, looking west towards Laos.

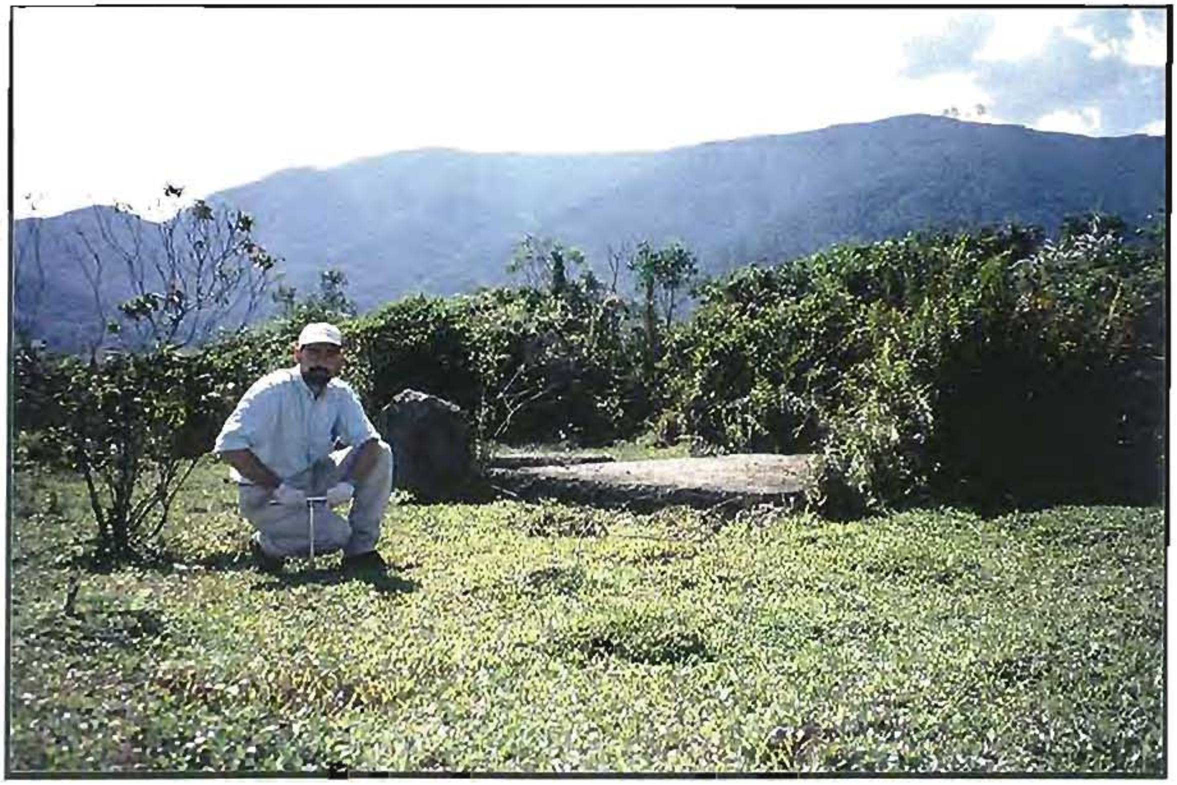

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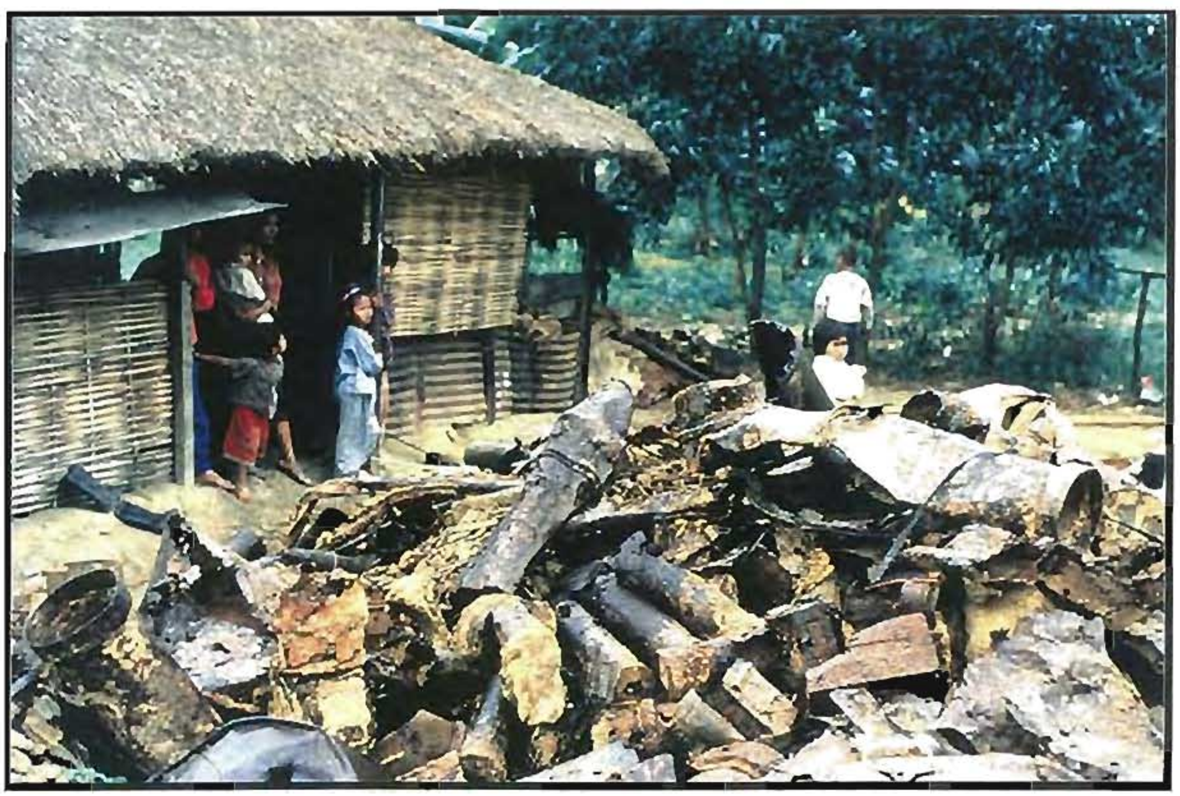
Plate 4.3: Remnants of A So Special Forces Base; collection of soil samples using stainless steel sampling device.



J. Newby

Plate 4.4: Collection of scrap metal from the war period is a dangerous yet common practice in Aluoi Valley.

J. Newby

Plate 4.5: Small children from Aluoi Valley.

J. Newby

Plate 4.6: Local Aluoi resident with woven basket commonly used for carrying wood and other items.

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Plate 4.7: Sampling river sediments at Con Cuong, our reference sampling area.

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Plate 4.8: Village of Con Cuong.

Hatfield Consultants Ltd.

Plate 4.9: Peoples' Committee Meeting, Gio An, 1997.

Hatfield Consultants Ltd.

Plate 4.10: Recording sampling data in the field.

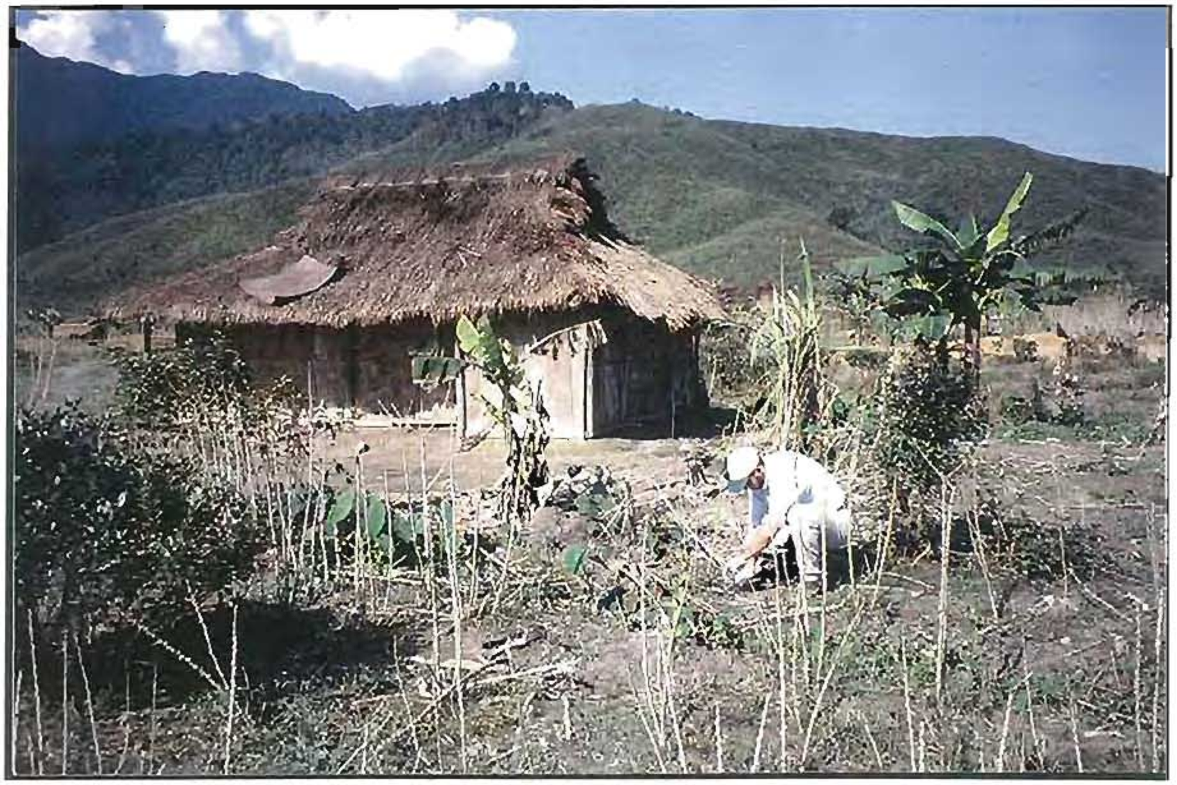

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Plate 4.11: Soil sampling in farmer's field, Aluoi (note barren hills in background).

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Plate 4.12: Soil core sample, collected to a maximum of 30 cm depth.

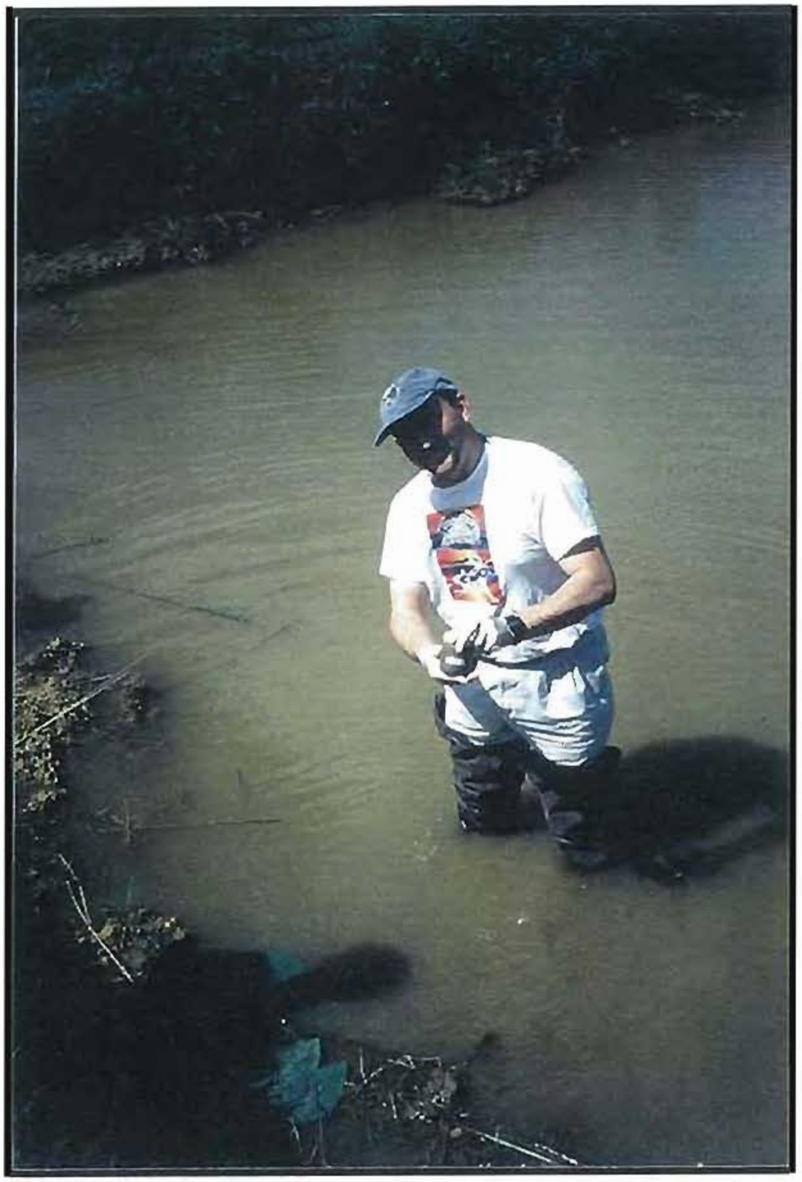

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Plate 4.13: Fishpond sediment sample collected in Aluoi Valley.

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Plate 4.14: Depositional sediment sampling area, A Sap River, Aluoi Valley.

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Plate 4.15: Grass carp (*Ctenopharyngodon idella*), an important cultured fish in Aluoi.

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Plate 4.16: Collection of grass carp from local fishponds.

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Plate 4.17: Fish dissection, including removal of skin and muscle tissue.

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Plate 4.18: Collection of manioc in Con Cuong.

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Plate 4.19: Sampling pig liver tissue, Aluoi Valley.

Plate 4.20: Dissection and sampling of duck tissues.

Plate 4.21: Dissection and sampling of chicken muscle.

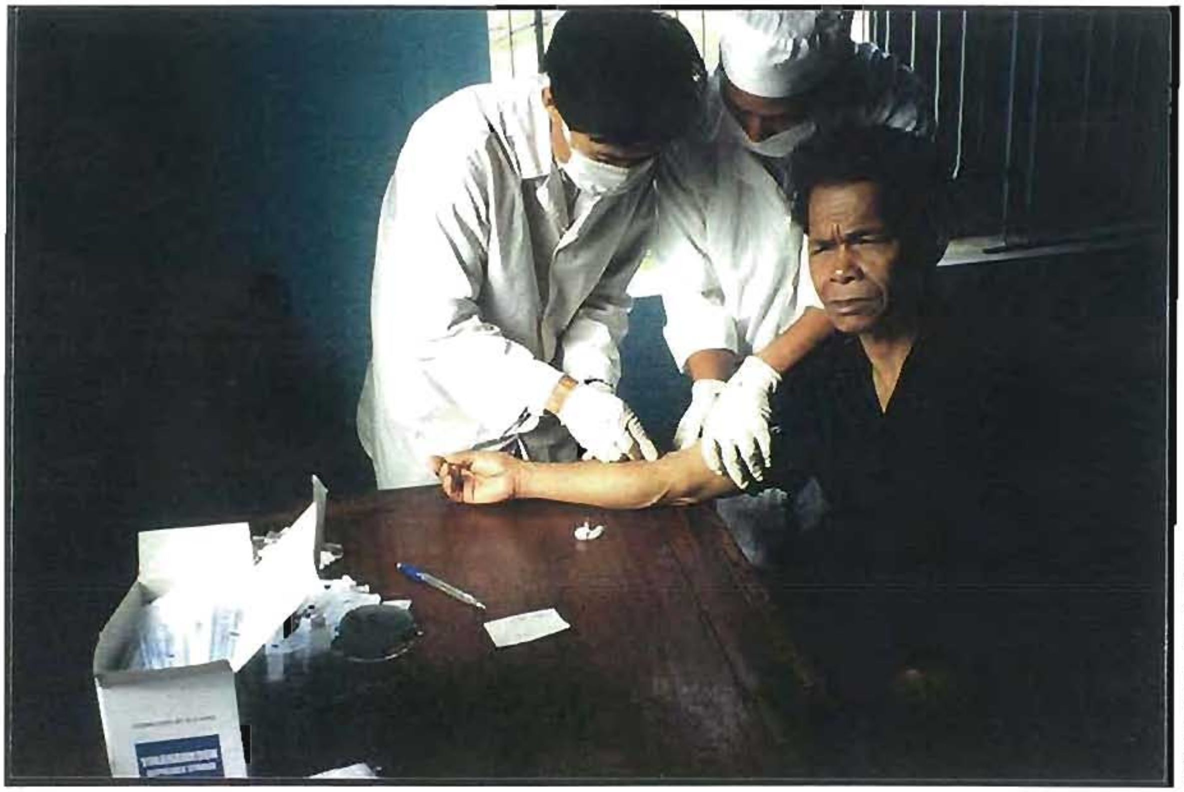

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Plate 4.22: Collection of blood samples from volunteer patient.

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Plate 4.23: Blood samples collected in Aluoi Valley.

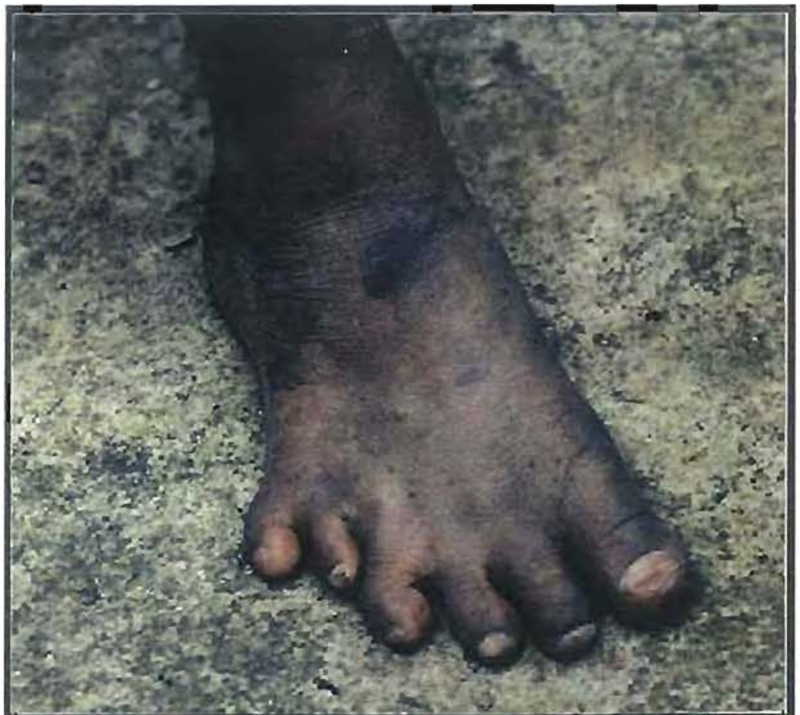

Plate 4.24: Observed in Aluoi Valley – Polydactylism.

J. Newby

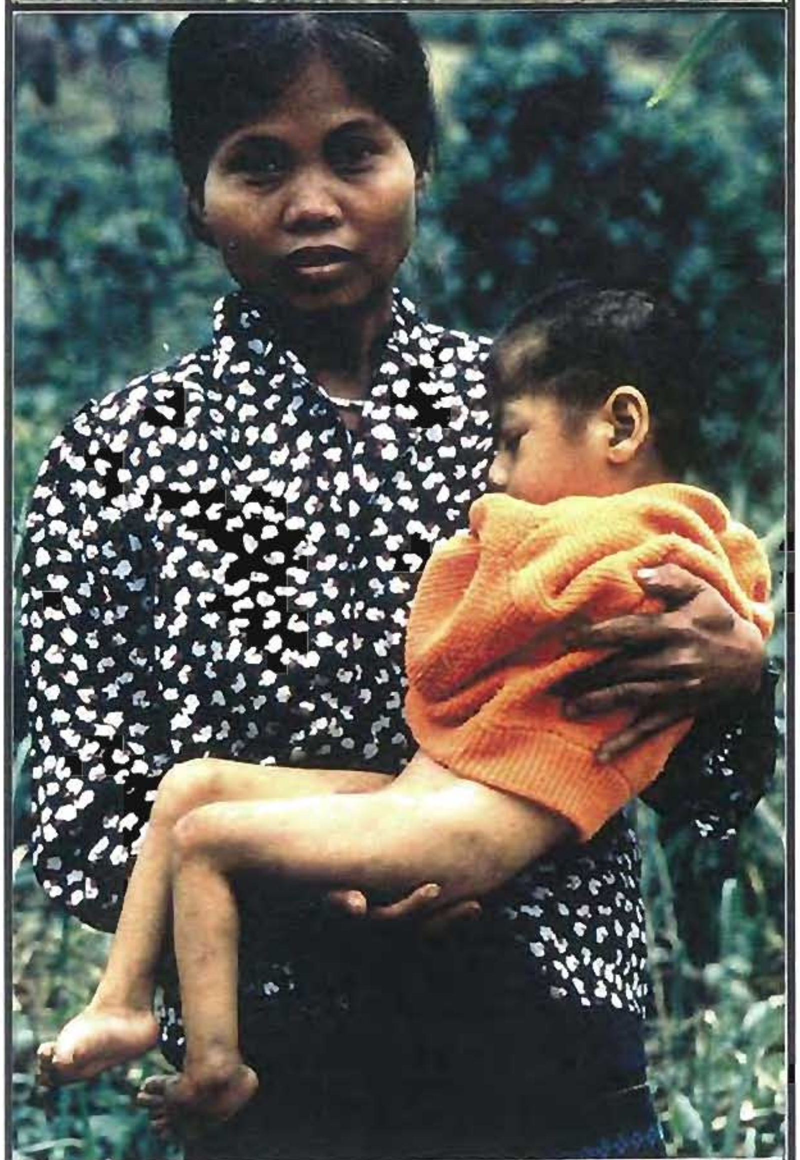

Plate 4.25: Observed in Aluoi Valley – Mental retardation and physical deformities.

J. Newby

SATELLITE IMAGES

PLATES 5.1 - 5.9

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Plate 5.1 Overview, Aluoi Valley, Central Viet Nam

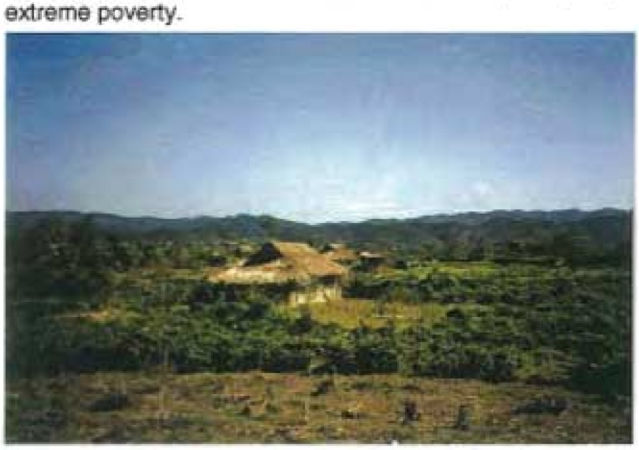
Sensor / Mode: *Radarsat-1 SAR, Standard Mode 7*
Date: *13 January 1997*
Scale: *1:250,000 (area coverage: 46 km x 60 km)*
Nominal resolution: *28 m*
Radarsat image © Canadian Space Agency.

Annotation and Feature Detection

Map Legend

- Aerial herbicide applications (1965 to 1971)
- GPS waypoints (November/December 1997)

The Aluoi valley was heavily sprayed with herbicides during the war, due to its strategic position on the Ho Chi Minh Trail. This area is very remote from the rest of Viet Nam, and people live in extreme poverty.



A Luoi, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:250 000 Scale

Kilometres 10 0 10

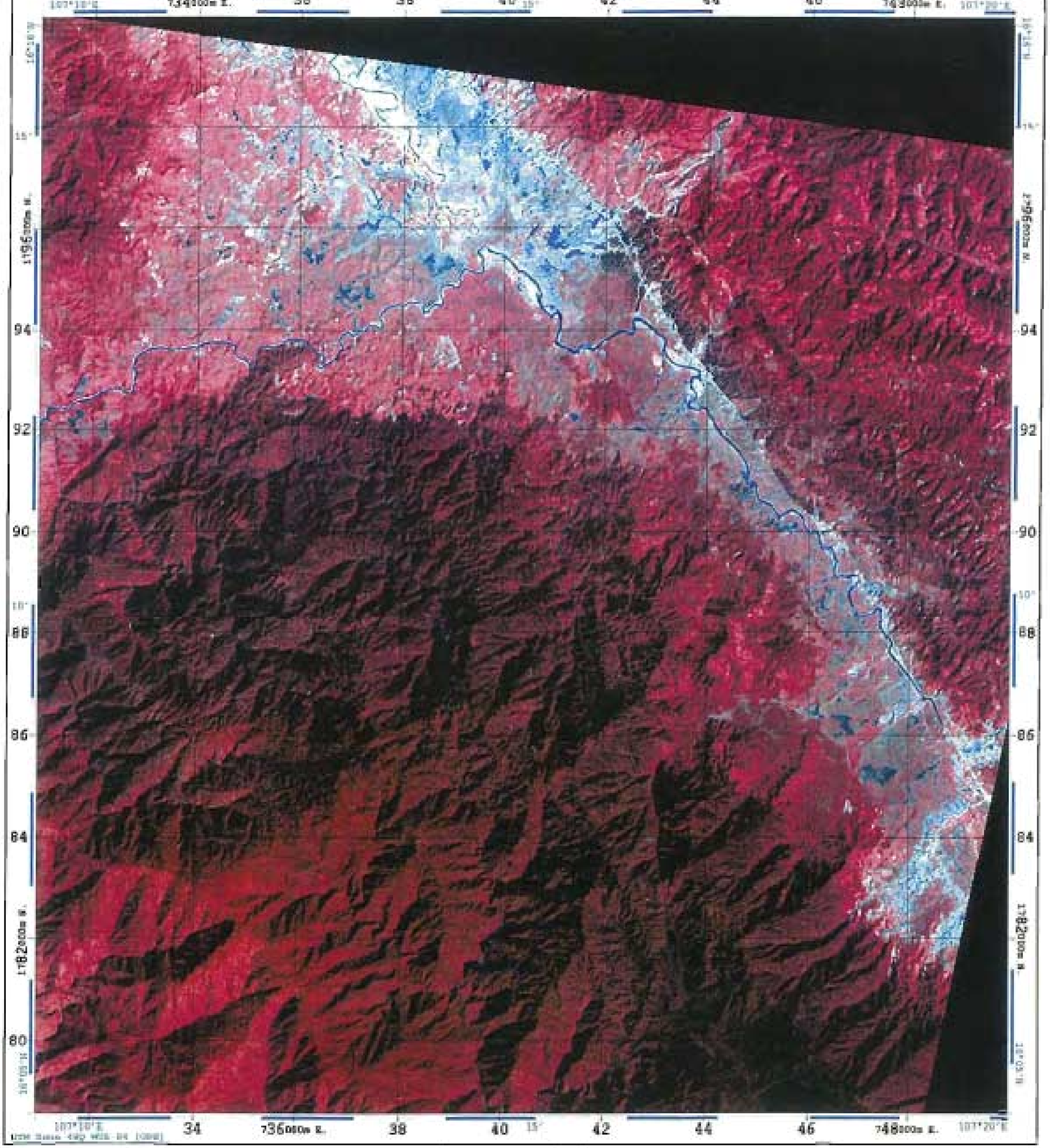
Miles 10 0 10

Plate 5.2 Aluoi Valley, Central Viet Nam

Sensor / Mode: *SPOT - XS*
Date: *3 May 1996*
Scale: *1:100,000 (area coverage: 19 km x 21 km)*
Nominal resolution: *20 m (SPOT)*

Annotation and Feature Detection

Barren hillsides near A So village, southern Aluoi valley. This photograph was taken in January 1996; in November 1997, the sparse banana plantation in the foreground had become much more dense.



A Luoi, Central Viet Nam

SPOT XS 3-2-1 False Colour Composite, 5-March-1996

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

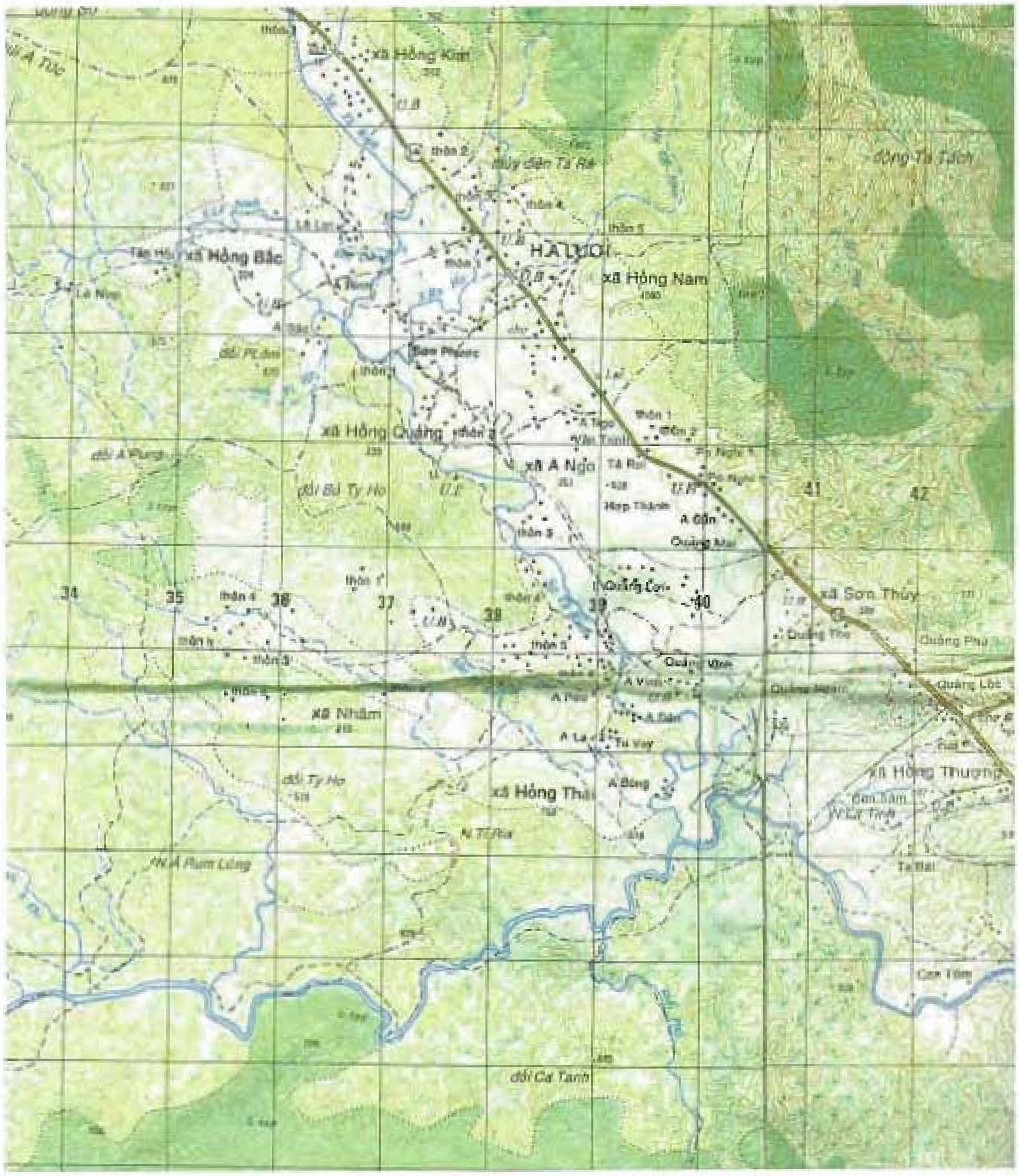
Miles 1 0 1 2 3 4 5

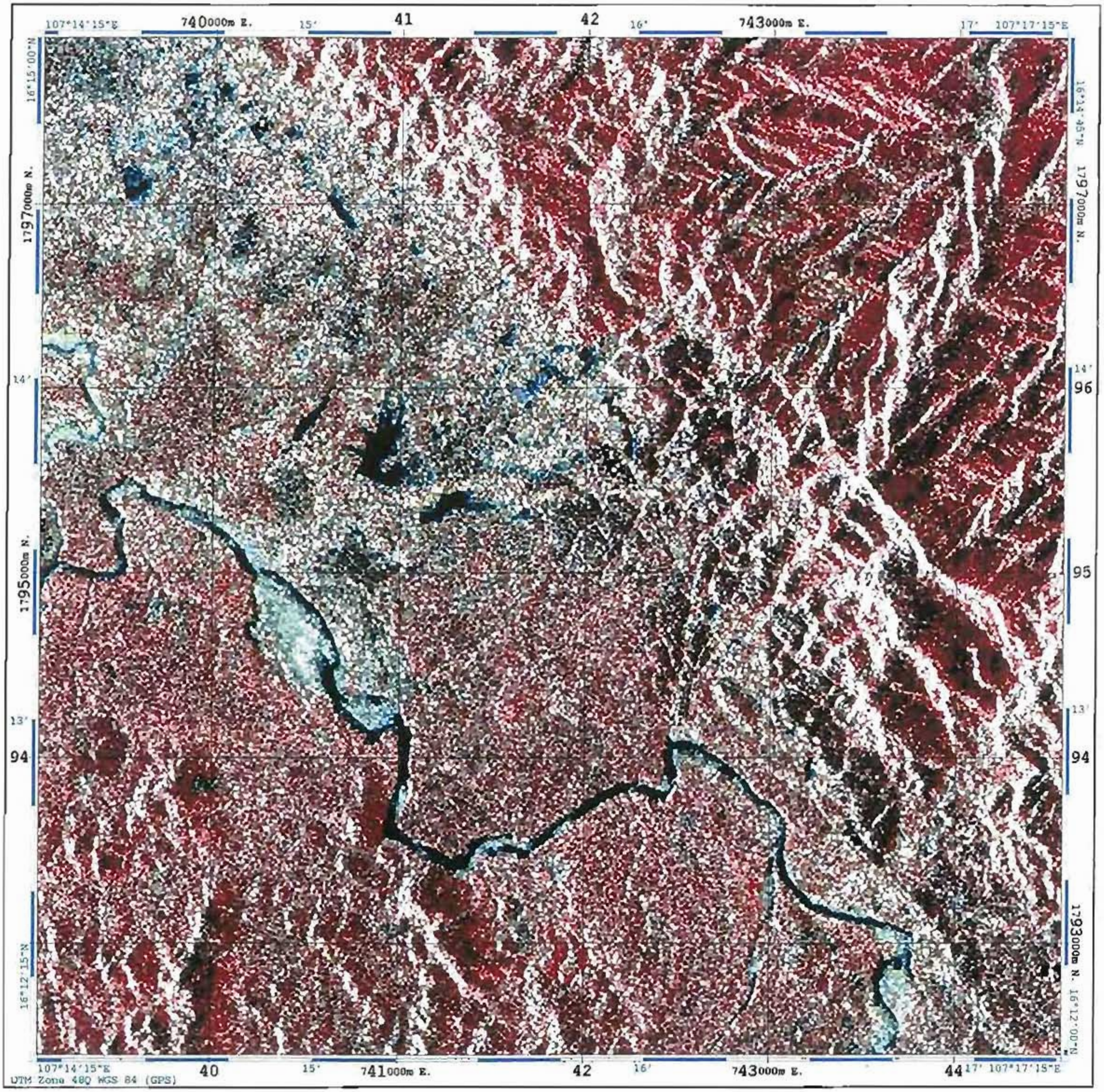
Plate 5.3 Detail, Northern Aluoi Valley

Sensor / Mode: *SPOT / XS and Radarsat-1 SAR, Fine Mode (F3)*
Dates: *3 May 1996 / 5 August 1996*
Scale: *1:30,000 (area coverage: 5 km x 5 km)*
Nominal resolution: *20 m (SPOT) and 8 m (Radarsat)*

Annotation and Feature Detection

Topography, amount of forest cover (green tones), and land use, northern Aluoi valley.
(Scan taken from 1:50,000-scale Vietnamese map E-48-131-C)





A Luoi, Central Viet Nam

RADARSAT F3 (5-8-96) integrated with SPOT XS 3-2-1 FCC (3-5-96)

1:30 000 Scale

Kilometres 1 0 1 2

Miles 1 0 1

Plate 5.4 Quang Tri Province and Former DMZ, Central Viet Nam

Sensor / Mode: *Radarsat-1 SAR, Standard Mode 7*
Acquisition Date: *13 January 1997*
Scale: *1:250,000 (area coverage: 60 km x 42 km)*
Nominal resolution: *28 m; original pixel spacing 12.5 m*
Radarsat image © Canadian Space Agency.

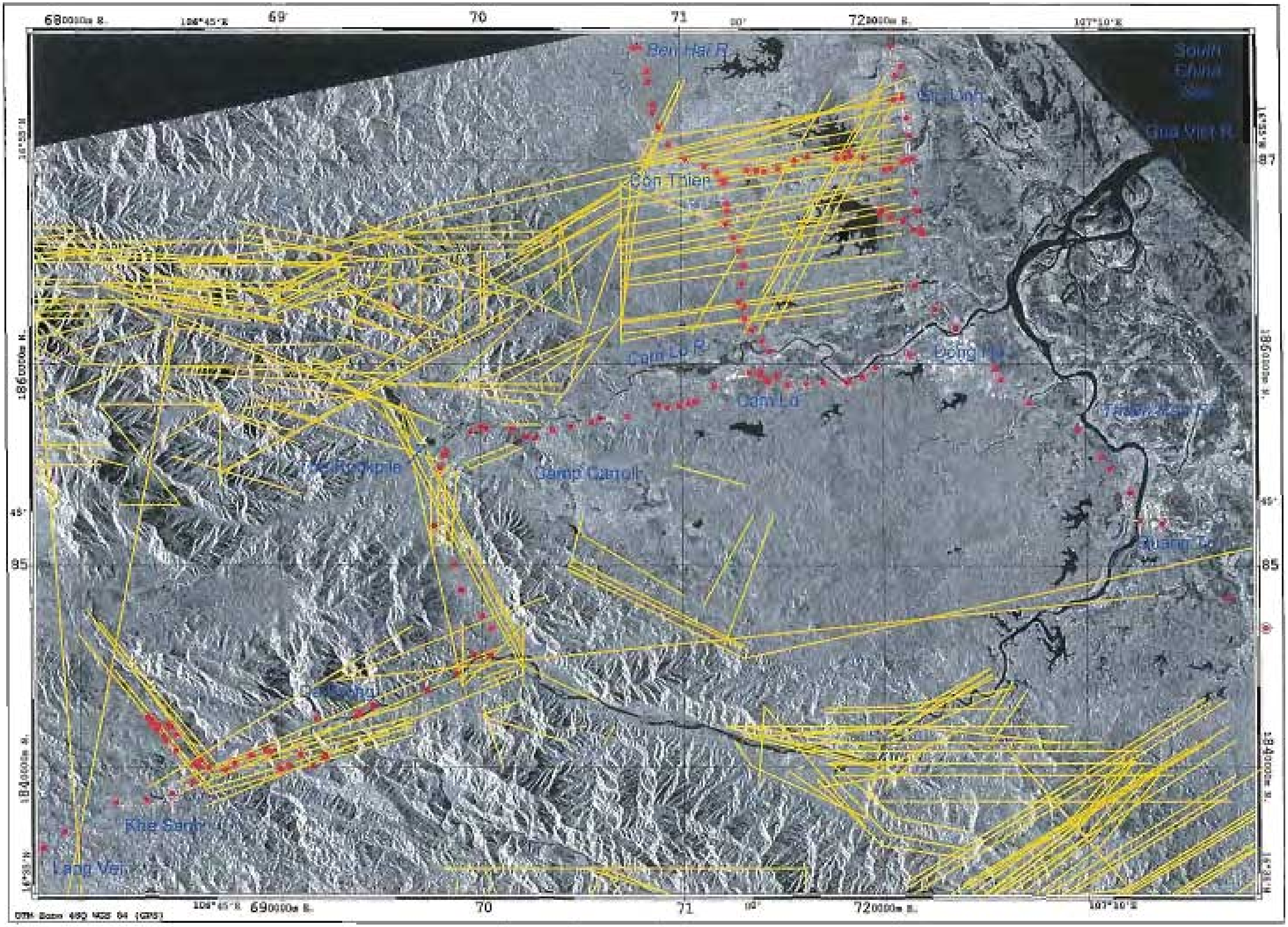
Annotation and Feature Detection

Map Legend

- Aerial herbicide applications (1965 to 1971)
- GPS waypoints (November/December 1997)

Comparing RADARSAT data with land-use maps near Dong Ha.

Near the Rockpile, former US artillery position, Highway 9, between Dong Ha and Khe Sanh.



Overview, Quang Tri Province and former DMZ, Central Viet Nam

RADARSAT STANDARD MODE (S7), 13-January-1997

1:250 000 Scale

Kilometres 10 0 10

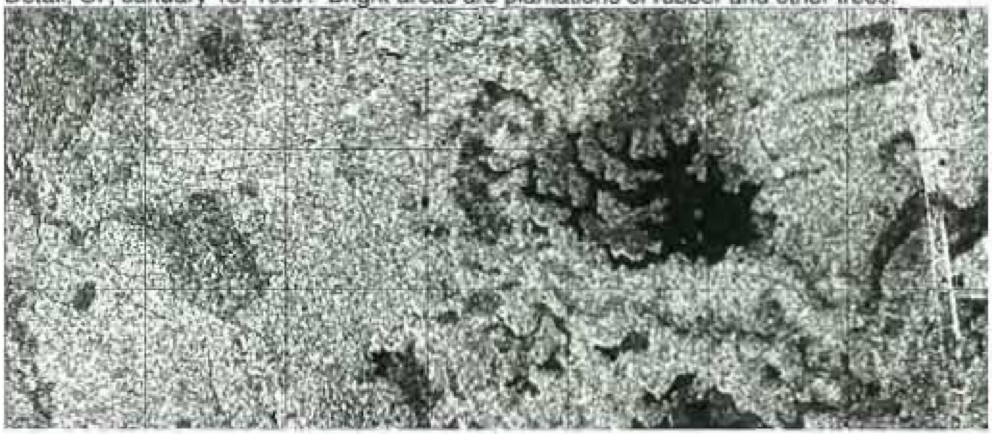
Miles 10 0 10

Plate 5.5 Dong Ha/Con Thien, Central Viet Nam

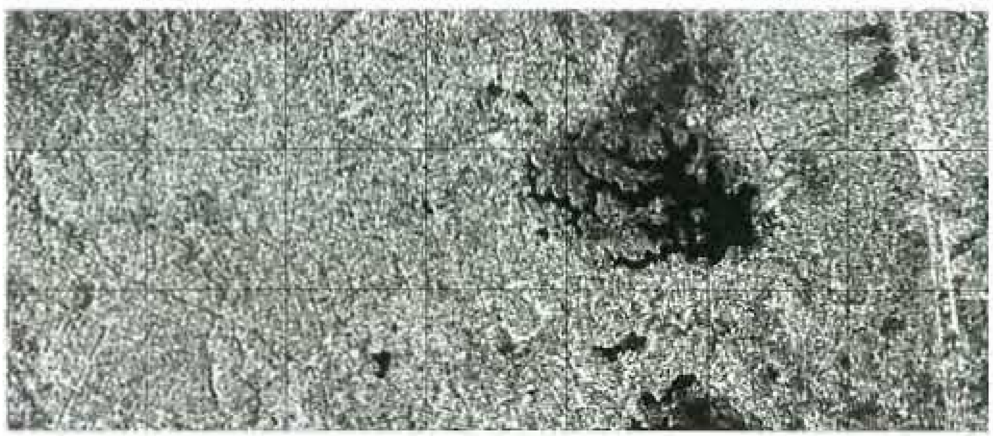
Sensor / Mode: *Radarsat-1 SAR, Standard Mode 7 (both dates)*
Dates: *13 January 1997 / 21 November 1997*
Scale: *1:100,000 (area coverage: 24 km x 17 km)*
Nominal resolution: *28 m*

Annotation and Feature Detection

Detail, S7, January 13, 1997. Bright areas are plantations of rubber and other trees.

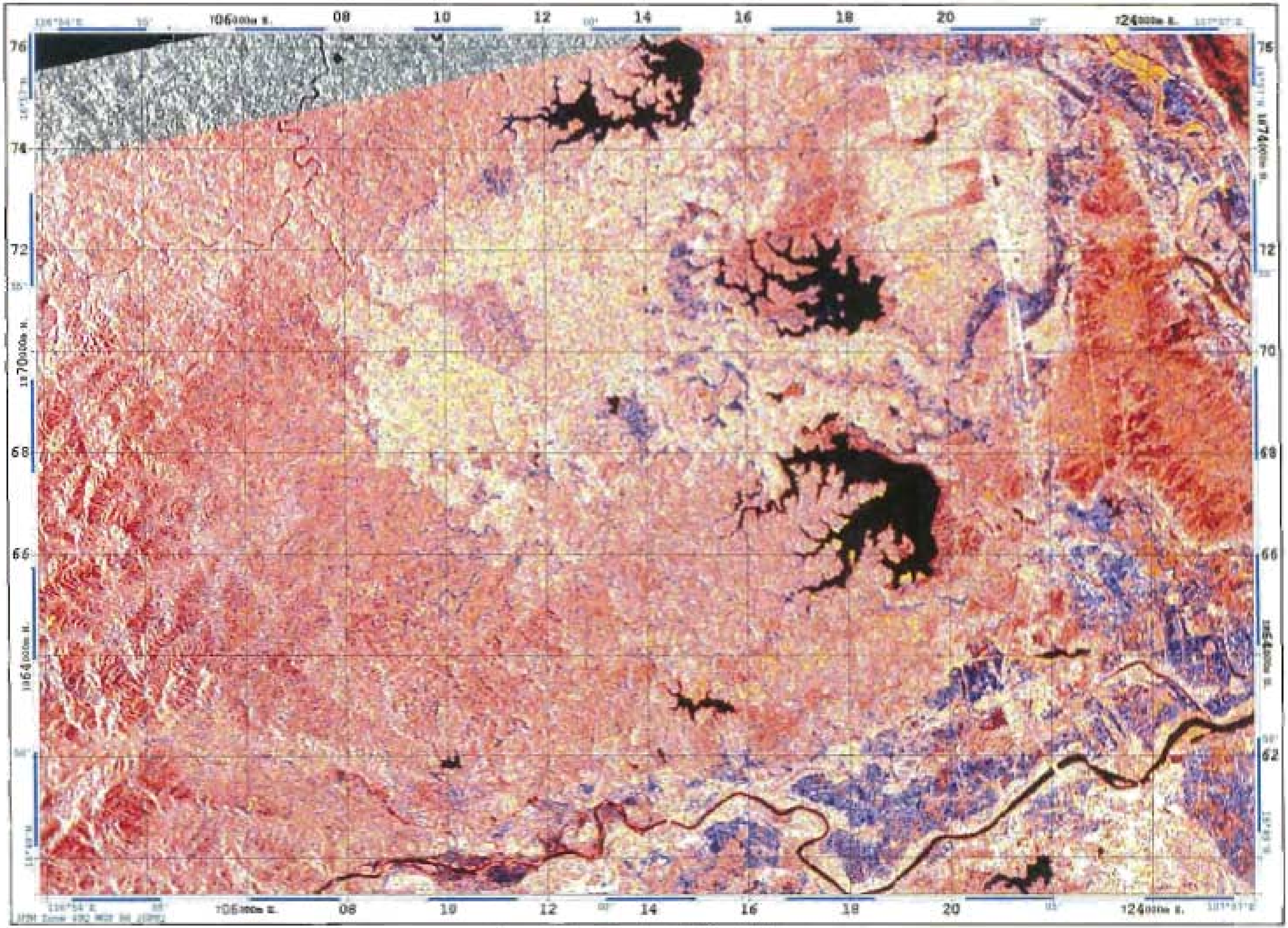


Detail, S7, November 21, 1997. Roads within and between rubber plantations visible (lower-left).



Barren land northeast of Dong Ha (centre-left in scene)

Low grasslands at edge or reservoir shown at left



Dong Ha, Central Viet Nam

RADARSAT STANDARD MODE S7a/S7b-S7a-S7b Composite, 13-1-97 (S7a) and 21-11-97 (S7b)

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5

Plate 5.6 Overview, Ma Da Upland Forest, Southern Viet Nam

Sensor / Mode: *Radarsat-1 SAR, Standard Mode (S7)*
Date: *15 August 1996*
Scale: *1:250,000 (area coverage: 48 km x 48 km)*
Nominal resolution: *28 m*
Radarsat image © Canadian Space Agency.

Map Legend

- Aerial herbicide applications (1965 to 1971)
- GPS waypoints (November/December 1997)

Many areas in the Ma Da region have not been rehabilitated since the war. This area, which was heavily sprayed by herbicides, remains barren and uncultivated.

While much of the region has not been rehabilitated, many areas have been replanted with various economic tree species, including rubber (below).

Overview, Ma Da Upland Forest, Viet Nam

RADARSAT STANDARD MODE (S7), 15-August-1996

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

Plate 5.7 Ma Da Upland Forest, Southern Viet Nam

Sensor / Mode:	*SPOT – XS (Bands 3-2-1)*
Date:	*5 March 1996*
Scale:	*1:100,000 (area coverage: 19 km x 22 km)*
Nominal resolution:	*20 m*

Annotation and Feature Detection

Regenerated forest, south of former Rang Rang airbase. Large standing trees are *Invingia* sp., which were resistant to herbicide application.

Barren herbicide-sprayed area north east of Rang Rang. Edge of uncultivated grasslands and regenerated forest is visible in the distance.

Ma Da Upland Forest, Viet Nam

SPOT XS 3-2-1 False Colour Composite, 5-March-1996

1:100 000 Scale

Kilometres 1 0 1 2 3 4 5 6 7

Miles 1 0 1 2 3 4 5

Plate 5.8 Overview, Ca Mau Peninsula, Southern Viet Nam

Sensor / Mode: *Radarsat-1 SAR, Standard Mode (S7)*
Date: *23 November 1997*
Scale: *1:250,000 (area coverage: 60 x 42 km)*
Nominal resolution: *28 m*

Map Legend

- Aerial herbicide applications (1965 to 1971)
- GPS waypoints (November/December 1997)

Tan An village, southern Ca Mau peninsula.

Shrimp farm, with mangroves newly planted between canals.

Overview, Ca Mau Peninsula, Southern Viet Nam

RADARSAT STANDARD MODE (S7), 19-August-1997

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10

Plate 5.9 Ca Mau Peninsula, Southern Viet Nam (1973)

Sensor / Mode	*Landsat-1 MSS (Bands 6-5-4):*
Dates:	*3 January 1973*
Scale:	*1:250,000 (area coverage: 60 km x 42 km)*
Nominal resolution:	*80 m*

Photograph of mangrove forest after herbicida application, Ca Mau peninsula.

(Photo from Fischer 1986)

Overview, Ca Mau Peninsula, Southern Viet Nam

LANDSAT-1 6-5-4 False Colour Composite, 3-January-1973

1:250 000 Scale

Kilometres 10 0 10

Miles 10 0 10