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5.6 Herbicides in Warfare: The Case of Indochina

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5.6.1 INTRODUCTION

The Second Indochina War (or Vietnam Conflict) of 1961–1975 is noted for the widespread and severe environmental damage inflicted upon its theatre of operations, especially in the former South Vietnam (Westing, 1976, 1980, 1982a, 1984b). The US strategy in South Vietnam, *inter alia*, involved massive rural area bombing, extensive chemical and mechanical forest destruction, large-scale chemical and mechanical crop destruction, wide-ranging chemical anti-personnel harassment and area denial, and enormous forced population displacements. In short, this US strategy represented the intentional disruption of both the natural and human ecologies of the region. Moreover, this war was the first in military history in which massive quantities of anti-plant chemical warfare agents (herbicides) were employed (Buckingham, 1982; Cecil, 1986; Lang *et al.*, 1974; Westing, 1976, 1984b).

The Second Indochina War was innovative in that a great power attempted to subdue a peasant army through the profligate use of technologically advanced weapons and methods. One can readily understand that the outcome of more than a decade of such war in South Vietnam and elsewhere in the region resulted not only in heavy direct casualties, but also in long-term medical sequelae. By any measure, however, its main effects were a widespread, long-lasting, and severe disruption of forestlands, of perennial croplands, and of farmlands—that is to say, of millions of hectares of the natural resource base essential to an agrarian society.

This section first reviews the history of the use of herbicides in warfare. It goes on to summarize the employment of these agents during the Second Indochina War against forest trees and crop plants, and then describes their immediate effect on flora and fauna. Following a brief treatment of the persistence of the agents used, it concludes with a summary of the long-term ecological effects, primarily with reference to South Vietnam.

5.6.2 HISTORICAL BACKGROUND

Humans, in common with all animals, are dependent upon the food and shelter they derive from the plant kingdom. The intentional military destruction during war of vegetation in territory under actual or potential enemy control is a recognition of this fundamental relationship. Indeed, crop destruction has been a continuing part of warfare for millennia (Westing, 1981a), and the military importance of forests has also long been recognized (Clausewitz, 1832–1834, pp. 426, 530).

Vegetational destruction can be accomplished via high explosives, fire, tractors, and other means. The account below describes the employment of chemical agents for this purpose. Indeed, the sporadic use of plant-killing chemicals during both peace and war is thousands of years old. Abimelech, the son of Jerubbaal and an ancient prophet and king of Israel, is recorded in the Bible as having sowed the conquered city of Shechem (at or near the modern Nablus, Jordan; approx. 50 km north of Jerusalem) with salt as the final, perhaps symbolic, act in its destruction (*Judges* 9:45). The ancient Romans seem also to have employed salt in this way (Scullard, 1961).

Various inorganic herbicides (including arsenicals) have been in routine agricultural and horticultural use since the late 19th century and a number of organic ones since the mid-1930s. However, the most important advance to date in the development of herbicides was the discovery of the remarkable utility of the phenoxy and other plant-hormone-mimicking chemicals. It is thus interesting to note that their development as herbicides was tied to the then secret chemical warfare research carried out by the British and US governments during World War II (Peterson, 1967).

More than a thousand chemicals were tested in the USA during World War II in the hopes of perfecting militarily usable crop-destroying chemicals (Merck, 1946, 1947; Norman, 1946). Clearly the single most important herbicidal compound developed during this period was 2,4-D, still the most widely used herbicide in the world. Its less used and more controversial cousin, 2,4,5-T, was developed in the same way during this period. Although the possibility was considered, herbicides were not used for military purposes during World War II.

It fell to the United Kingdom in its attempt to suppress an insurgency in Malaya to be the first to employ modern herbicides for military purposes, primarily during the mid-1950s (Clutterbuck, 1966; Henderson, 1955; Henniker, 1955). The chemical anti-plant agents were used for two different purposes in this desultory decade-long war. Some of the herbicidal attacks were for defoliation along lines of communication in order to reduce the possibility of ambushes, whereas others were for the destruction of crops which were presumably being grown by or for the insurgents. These applications (both by air and from the ground) were relatively modest and rather short-lived.

The major agent employed appears to have been a mixture of 2,4,5-T, 2,4-D, and trichloroacetic acid (Connor and Thomas, 1984).

The only really large-scale military use of herbicides was by the USA in pursuing the Second Indochina War. This programme, the details of which are presented below, began on a very small scale in 1961, increased to a crescendo in 1969, and finally ended during 1971. Although the major US effort was directed against forests, a continuing aspect of the programming from beginning to end was crop destruction and food denial. Through the years, the US herbicide spraying was confined largely to South Vietnam, but a modest fraction of eastern Kampuchea was also involved once in 1969 (Westing, 1972). Moreover, the USA also carried out a series of herbicide missions against Laos (Westing, 1981b) and possibly a few against North Vietnam as well (Agence France Presse, 1971).

Other than the above-noted instances, herbicides have been associated with other theatres of war and with the armed forces of other nations to only a very limited extent. For example, in 1972 the Israeli Army used 2,4-D on one occasion for crop destruction in Aqaba, Jordan (approx. 40 km north-northeast of Jerusalem) (Holden, 1972) and thus amazingly close to the Shechem mentioned earlier, where one of the first military uses of herbicides may have occurred some three thousand years ago.

5.6.3 THE SECOND INDOCHINA WAR OF 1961–1975

5.6.3.1 Technical Background

During the Second Indochina War, the USA carried out a massive herbicidal programme that stretched over a period of a decade. Although the USA was neither the first nor the only nation to employ chemical anti-plant agents as weapons of war, the magnitude of this programme was without precedent. It was aimed for the most part at the forests of South Vietnam and, to a lesser extent, at its crops. Herbicidal attacks upon the other nations of Indochina were modest in comparison. Using a variety of agents, the USA eventually expended a volume of more than 72 million litres (91 million kilograms), containing almost 55 million kilograms of active herbicidal ingredients.

The major anti-plant agents that were employed by the USA in Indochina were colour-coded 'Orange', 'White', and 'Blue' (Table 5.6.1). Agents Orange and White consist of mixtures of plant-hormone-mimicking compounds which kill by interfering with the normal metabolism of treated plants; Agent Blue, on the other hand, consists of a desiccating compound, which kills by preventing a plant from retaining its moisture. Agents Orange and White are particularly suitable for use against dicotyledonous plants, whereas Agent Blue is relatively more suitable for use against monocotyledonous plants. At the high levels that were used for military application—28 l/ha, averaging 21 kg/ha in terms of active ingredients (i.e. 20 to 40 times higher than normal civil usage)—these

Table 5.6.1 Major chemical anti-plant agents employed by the USA in the Second Indochina War. Source: Westing (1976) adjusted in accord with Westing (1982b)

Type	Composition	Physical properties	Application
Agent Orange*	A 1.124:1 mixture (by weight) of the *n*-butyl esters of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) (545.4 kg/m^3 acid equivalent) and 2,4-dichlorophenoxyacetic acid (2,4-D) (485.1 kg/m^3 acid equivalent); also containing 2,3,7,8-tetrachloro-p-dioxin (dioxin) (an estimated 3.83 g/m^3)	Liquid; oil-soluble; water-insoluble; weight 1285 kg/m^3	Applied undiluted at 28.06 l/ha, thereby supplying 15.31 kg/ha of 2,4,5-T and 13.61 kg/ha of 2,4-D, in terms of acid equivalent, and also an estimated 107 mg/ha of dioxin
Agent White	A 3.882:1 mixture (by weight) of the tri-iso-propanolamine salts of 2.4-dichlorophenoxyacetic acid (2,4-D) (239.7 kg/m^3 acid equivalent) and 4-amino-3,5,6-trichloropicolinic acid (picloram, 'Tordon') (64.7 kg/m^3 acid equivalent)	Aqueous solution; oil-insoluble; weight 1150 kg/m^3	Applied undiluted at 28.06 l/ha, thereby supplying 6.73 kg/ha of 2,4-D and 1.82 kg/ha of picloram in terms of acid equivalent
Agent Blue	A 2.663:1 mixture (by weight) of Na dimethyl arsenate (Na cacodylate) and dimethyl arsinic (cacodylic) acid (together 371.46 kg/m^3 acid equivalent)	Aqueous solution; oil-insoluble; weight 1310 kg/m^3	Applied undiluted at 28.06 l/ha, thereby supplying 10.42 kg/ha, in terms of acid equivalent (of which 5.66 kg/ha is elemental arsenic).

*Numerous herbicidal formulations have been tested by the USA as chemical anti-plant agents, several of which were assigned a colour code during their more or less ephemeral existence: 'Orange II' was similar to the 'Orange' above, except that its 2,4,5-T moiety was replaced by the iso-octyl ester of 2,4,5-T; 'Pink' was a mixture of the *n*-butyl and iso-butyl esters of 2,4,5-T; 'Green' consisted entirely of the *n*-butyl ester of 2,4,5-T; and 'Purple' was a mixture of the *n*-butyl ester of 2,4-D and the *n*-butyl and iso-butyl esters of 2,4,5-T herbicides are, however, not as selective as one might expect on the basis of civil experience.

Of the several agents used, Agent Orange represented 61% of the total volume expended over the years (Table 5.6.2). The three peak years of herbicide spraying—1967 to 1969—were about equal in magnitude and together accounted for over three-quarters of the volume of total US wartime expenditures. These were also very active war years in other respects, as evidenced, for example, by the heavy US munition expenditures during this period and the high numbers of US fatalities.

Forest destruction was generally accomplished through the use of Agents Orange or White. Conversely, Agent Blue was usually the agent of choice for the destruction of rice and other crops, although Agent Orange was much used for this purpose as well (Table 5.6.3). All told, about 86% of the missions were

Table 5.6.2 US herbicide expenditures in the Second Indochina War: a breakdown by agent and year* (in $m^3 = 10^3$ l). Source: Westing (1976). Reproduced with permission

Year	Agent Orange†	Agent White‡	Agent Blue§	Total¶
1961	?	0	?	?
1962	56	0	8	65
1963	281	0	3	283
1964	948	0	118	1066
1965	1767	0	749	2516
1966	6362	2056	1181	9599
1967	11 891	4989	2513	19 394
1968	8850	8483	1931	19 264
1969	12 376	3572	1309	17 257
1970	1806	697	370	2873
1971	0	38	?	38
Total‖	44 338	19 835	8182	72 354

*To convert any of the herbicide volume data given to area covered in hectares (not considering overlap), multiply by 35.6

†To convert any of the Agent Orange volume data given to total weight in kilograms, multiply by 1285; similarly for 2,4,5-T content in kilograms, multiply by 545; similarly for 2,4-D, multiply by 485; similarly for dioxin estimate, multiply by 0.003 83

‡To convert any of the Agent White volume data given to total weight in kilograms, multiply by 1150; similarly for 2,4-D content in kilograms, multiply by 240; similarly for picloram, multiply by 64.7

§To convert any of the Agent Blue volume data given to total weight in kilograms, multiply by 1310; similarly for dimethyl arsinic (cacodylic) acid in kilograms, multiply by 371; similarly for elemental arsenic, multiply by 202

¶To convert any of the total herbicide volume data given to average total weight in kilograms, multiply by 1251; similarly for average kilograms of active ingredients, multiply by 757

‖The following amounts were sprayed in terms of active ingredients: 2,4-D, 26 million kilograms; 2,4,5-T, 24 million kilograms (containing about 170 kg dioxin); picloram, 1.3 million kilograms; dimethyl arsinic (cacodylic) acid, 3.0 million kilograms (of which elemental arsenic represents 1.7 million kilograms): total active ingredients, 55 million kilograms directed primarily against forest and other woody vegetation and the remaining 14% primarily against crop plants.

Total geographical coverage of the spray missions was less than one might expect on the basis of the total expenditure of herbicides, since about 34% of the target areas were chemically attacked more than once during the course of the war (Table 5.6.4). Thus the total area subjected to spraying one or more times came to an estimated 1.7 million hectares, this area being treated 1.5 times on average, thereby receiving an average dose of approx. 42 l/ha, or approx. 32 kg/ha in terms of active ingredients.

Most of the anti-plant chemicals—in the neighbourhood of 95%—were dispersed from C-123 (UC-123) transport aircraft equipped to deliver somewhat over 3000 l onto 130 ha or so. The high-pressure nozzles which were used delivered droplets having an approximate median diameter of 350 μm, so that there was reasonably little drift as long as wind speeds exceeding 5 m/s were

Table 5.6.3 US herbicide expenditures in the Second Indochina War: a breakdown by type of mission and agent* (in m^3). Source: Westing (1976). Reproduced with permission

Type of mission	Agent Orange	Agent White	Agent Blue	Total
Forest	39 816	19 094	1684	60 594
Misc. woody vegetation	709	529	312	1550
Crop	3813	212	6185	10 210
Total	44 338	19 835	8182	72 354

*The same conversions provided in Table 5.6.2 footnotes are also applicable to this table

Table 5.6.4 US herbicide expenditures in the Second Indochina War: a breakdown by number of repeat sprayings within the area covered. Source: Westing (1976). Reproduced with permission

Number of sprayings of one area	Ultimate herbicide expenditure* (m^3)	Area involved† (10^3 ha)
One	31 572	1125
Two	21 431	382
Three	11 412	136
Four	5335	48
Five or more	2603	19
Total	72 354	1709

*To convert any of the herbicide volume data given to average total weight in kilograms, multiply by 1251; similarly for average kilograms of active ingredients, multiply by 757

†Based on the standard application rate of 28.1 l/ha. Had no area been sprayed more than once, then the total coverage would have been 2578×10^3 ha. As it was, the areas which were sprayed received an overall average of 42.3 l/ha, that is, they were sprayed an average of 1.51 times

avoided, as they usually were. Normal spray time for an aircraft was just over 2 minutes, although the entire payload could, if the need arose, be ejected (dumped) in about 30 seconds, and thus onto approximately 30 hectares. Of the order of 50 such dumpings occurred during the war, in which the dose level became approx. 120 l/ha, or about 90 kg/ha in terms of active ingredients. One aircraft (one sortie) sprayed a strip roughly 150 m wide and 8.7 km long. A mission generally consisted of 3–5 aircraft flying in lateral (side-by-side) formation. Most of the 5% of the anti-plant chemicals not dispensed from fixed-wing aircraft was dispensed from helicopters, although small amounts were also dispensed from trucks and boats.

It is impossible to provide an accurate regional breakdown of herbicide expenditures for the whole of Indochina inasmuch as the necessary information has never been made public by the USA. It is known that about 10% of South Vietnam, the hardest hit nation, was sprayed (Table 5.6.5). Within South Vietnam, it was a rather large region surrounding Saigon (Ho Chi Minh City)—so-called Military Region III (Figure 5.6.1)—that was singled out for the most intensive coverage, both on a per-unit-area or per-capita basis. Indeed, it appears that essentially 30% of the land area of Military Region III was sprayed one or more times.

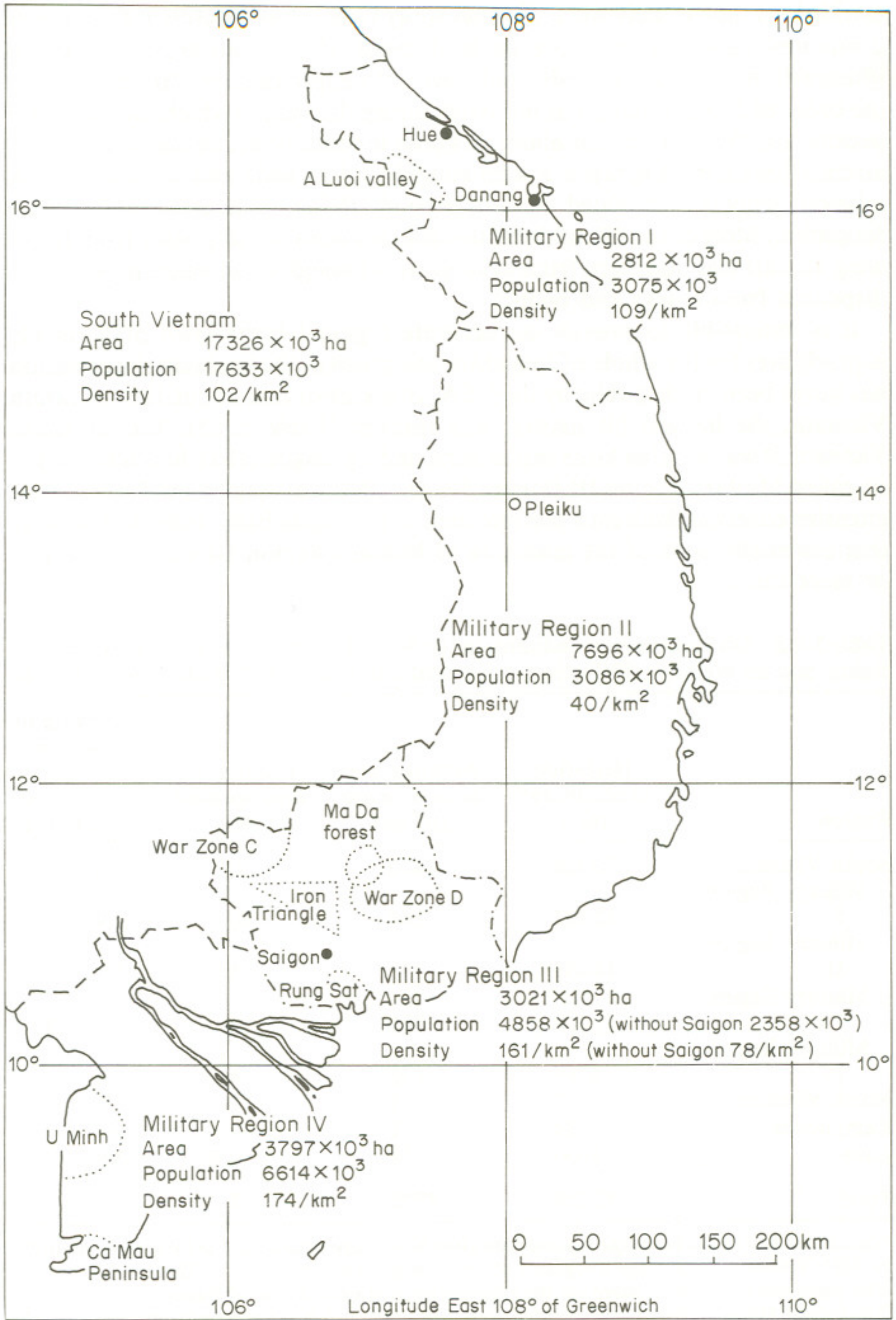
Table 5.6.5 US herbicide expenditures in the Second Indochina War: a breakdown by region. Source: Westing (1976) adjusted in accord with Westing (1972) and Westing (1981b)

Region	Herbicide expenditure* (m^3)	Area sprayed once or more (10^3 ha)	Fraction of area sprayed (%)	Spraying in relation to the population (l/capita)
South Vietnam‡	70 720	1670	10	4.0
Military Region I	12 022	284	10	3.9
Military Region II	14 851	351	5	4.8
Military Region III	37 482	885	29	7.7(15.9)†
Military Region IV	6365	150	4	1.0
North Vietnam	?	?	?	?
Kampuchea	34	1	—	—
Laos	1600	38	0.2	0.6
Total	72 354	1709	2	1.6

*To convert any of the herbicide volume data given to average total weight in kilograms, multiply by 1251; similarly for average kilograms of active ingredients, multiply by 757

†The parenthetical value is based on the regional population less that of Saigon

‡The former Military Regions are depicted, and their areas and mid-war populations provided, in Figure 5.6.1



Source: Westing (1976, pages 3,7).

5.6.3.2 Immediate Effects on Flora and Fauna

Dense Inland (Upland) Forest

Woody vegetation covers about 10.4 million hectares, or 60%, of South Vietnam, the largest single category of which is dense inland (upland) forest. The dense inland forest, extending over about 5.8 million hectares, is composed of a complex and variable floristic conglomeration. It includes a bewildering diversity of dicotyledonous trees, lianas, epiphytes, and herbs, as well as some monocotyledons, ferns, etc. The tree species vary in height, usually forming two and occasionally three rather indistinct strata (storeys). The upper canopy usually attains a height of 20–40 m. The dominant plant family is the Dipterocarpaceae, which is represented by at least 30 major species in the genera *Dipterocarpus*, *Anisoptera*, *Hopea*, and *Shorea*. Another important genus is *Lagerstroemia* in the family Lythraceae. There are also a number of important genera of Leguminosae (e.g. *Erythrophleum*), Guttiferae, and Meliaceae. Moreover, this dense inland forest supports some 200 commercial tree species, a dozen of which are of exceedingly high quality and suitable for the world market. Chief among these so-called luxury woods are three rosewood species (*Dalbergia bariensis*, *D. cochinchinensis*, and *Pterocarpus pedatus*; all Leguminosae), an ebony (*Diospyros mun*; Ebenaceae), and a false mahogany (*Melanorrhea laccifera*; Anacardiaceae).

The dense inland forest was the militarily most important of South Vietnam's land categories. To begin with, it can be estimated that about 1.4 million hectares, or 14% of the total extent of South Vietnam's woody vegetation was sprayed one or more times (Table 5.6.6). Of this, perhaps 1.1 million hectares occurred in the dense inland forest type, which represents about 19% of that vegetational category. The dense forest lands within so-called War Zones C and D (Figure 5.6.1) were particularly hard hit.

Following herbicidal attack of an inland forest, fairly complete leaf abscission (as well as flower and fruit abscission) occurred within two or three weeks. The surviving trees usually remained bare until the onset of the next rainy season, often, therefore, for a period of several or more months. To achieve total defoliation of the lower storeys of a multiple-canopy forest necessitated one or more follow-up sprayings.

Virtually all of the many dicotyledonous tree species subjected to spraying were defoliated at the intensity of treatment employed. Then, at the time of refoliation, a spectrum of sensitivity became evident among the many hundreds of tree species which comprise this vegetational type. Among the most sensitive of the dense inland forest species of South Vietnam are *Pterocarpus pedatus* (Leguminosae) and *Lagerstroemia* spp. (Lythraceae). Among the most resistant

Figure 5.6.1 *(opposite)* South Vietnam during the Second Indochina War (populations shown are estimates for 1969). Source: Westing (1976). Reproduced by permission

Table 5.6.6 US herbicide expenditures, in 10^3 ha, in South Vietnam in the Second Indochina War: a breakdown by vegetational type. Source: Westing (1976) adjusted in accord with Table 5.6.5

Vegetational type	Area	Area sprayed once or more
Dense forest	5800	1077
Primary	4500	836
Primary plus secondary	600	111
Secondary	700	130
Open (clear) forest	2000	100
Bamboo brake	800	40
Mangrove forest (swamp)	500	151
True	300	124
Rear (back)	200	27
Rubber plantation	100	30
Pine forest	100	0
Miscellaneous woody vegetation	1100	36
Woody subtotal	10 400	1434
Paddy (wet) rice	2500	59
Field crops (upland rice, etc.)	500	177
Agricultural subtotal	3000	236
Miscellaneous	3926	0
Total	17 326	1670

are *Cassia siamea* (Leguminosae) and *Sandoricum indicum* (Meliaceae). And among those intermediate between these two extremes are *Hopea odorata*, *Dipterocarpus alatus*, and *Shorea cochinchinensis* (all Dipterocarpaceae).

Only about 10% (some observers have suggested more) of the trees were killed outright by a single military spraying, a situation true for perhaps 66% of the total sprayed area (Table 5.6.4). The survivors displayed various levels of injury, as evidenced by differing severities of crown (branch) dieback, temporary sterility, and other symptoms. Such injury in time resulted in some further delayed mortality among the survivors. Moreover, once the understorey was deprived of the protection of the overstorey, some fraction of the understorey trees in time die of environmental conditions too harsh for their existence. When the military situation led to more than one herbicidal attack, as occurred on about 34% of all sprayed lands, the level of tree mortality increased more or less exponentially with each subsequent spraying, more steeply so with briefer intervals between sprayings. It might also be noted that in economic terms the spraying of South Vietnam's dense inland forest resulted in a loss of commercial timber estimated to be of the order of 20 million m^3 (Westing, 1980, 1982a).

When the trees were sprayed, causing the leaves to fall and decompose, the soil was for the most part unable to hold the released nutrients so that these were lost to the local ecosystem, a phenomenon referred to as nutrient dumping, which is especially acute in the tropics. Further nutrient losses and other site debilitation occurred, since the death of the vegetation led to accelerated soil erosion. Both erosion and nutrient dumping continued until the area in question was again stabilized by the establishment of a replacement (pioneer) vegetation, usually during the subsequent growing season.

The principal impact on the wildlife of sprayed sites was via a diminution in the food and cover (shelter) afforded by the vegetation. Here it must be noted that a significant majority of the animal life in a tropical forest is found in—and depends upon—the upper vegetational storeys, precisely the portion of the ecosystem most seriously impaired by massive herbicidal attack. There was also a more or less modest level of damage to wildlife via the direct toxic action of the herbicides sprayed. Some birds appear to have succumbed in this fashion, and probably several kinds of invertebrates as well, including some aquatic invertebrates and some terrestrial insects.

Thus it can be seen that the immediate ecological impact of military spraying of an inland forest site with anti-plant chemicals can be severe, especially if repeated. The primary producers (green plants) of an ecosystem are knocked back drastically, to be replaced by a new community of significantly lesser biomass, smaller nutrient-holding capacity, and reduced primary productivity. A poorer soil results from the attack, with a lesser fraction of humus (organic matter), and often exhibiting a chronic shortage of nitrogen. Fire subsequent to herbicidal attack would aggravate the situation. Particularly in those inland areas that were sprayed several times—some 200 thousand hectares (Table 5.6.4)—the overstorey destruction was sufficient to permit the release of, or invasion by, certain tenacious pioneer grasses. These included both herbaceous types, such as *Imperata cylindrica* (Gramineae), and woody types, such as frutescent (shrubby) bamboos.

Coastal Mangrove Habitat

The mangrove habitat, scattered primarily along the southerly coastline of South Vietnam, occupies approximately 500 thousand hectares of inhospitable, seemingly impenetrable, and outwardly unimportant swamps. The dominant mangrove vegetation consists of several species of small trees, mostly 3 m to 15 m high, primarily in the genera *Rhizophora* (Rhizophoraceae), *Avicennia* (Verbenaceae), and *Bruguiera* (Rhizophoraceae)—all so-called mangroves. As soil deposition extends the coastline slowly out into the sea, the most common pioneer of this virgin land is *Sonneratia* (Lythraceae), which in turn prepares the site for a subsequent invasion by *Avicennia*. *Rhizophora* is likely to be next in this succession, to be followed by *Bruguiera*, which extends back to the limit of daily tidal wash (and the limit of the true mangrove type). Through time, the soil level builds up beyond the reach of flood tide and a new community (the rear (or back) mangrove type) develops, which is dominated by a tree species of *Melaleuca* (Myrtaceae). The mangrove habitat provides substantial amounts of firewood, charcoal, tannin, thatch (from *Nipa fruticans*; Palmae), and other secondary forest products.

The mangrove habitat is singled out here owing to the widespread and peculiarly drastic herbicidal damage it suffered during the Second Indochina War. An estimated 124 thousand hectares of true mangrove—41% of that entire sub-type—plus another 27 thousand hectares of rear mangrove (13% of that sub-type) were subjected to military herbicide spraying during the war. Unlike the relatively modest degree of kill resulting from such action in inland forest types, even a single spraying in this coastal lowland type most often destroyed essentially the entire plant community (the herbicidal sensitivity probably being related to its osmotic versatility, i.e. to its wide tolerance to changes in salinity). Virtually nothing remained alive after a single herbicidal attack and the resulting scene was weird and desolate. It subsequently became even worse when exacerbated by the usual salvage harvesting of the killed trees and by the inevitable erosion.

The taxonomically diverse plant species that make up the mangrove community all displayed great sensitivity to the hormone-mimicking herbicides, with *Rhizophora*—the economically most important genus of trees—being especially sensitive, and *Avicennia* somewhat less so (Truman, 1961–1962; Walsh *et al.*, 1973). Little if any immediate recolonization occurred on the herbicide-obliterated sites. With the primary producers essentially wiped out, their energy-capturing function was lost, along with all else that built on this. Both food and cover were eliminated by the US attacks, affecting not only the enemy forces but the indigenous forest creatures as well. For example, an enormous reduction was reported in numbers of birds (Orians and Pfeiffer, 1970).

Less obviously, the reticulation of channels throughout a mangrove swamp—roughly one-quarter of the surface area of the mangrove type in South Vietnam—supports a rich variety of aquatic fauna during all or part of their life cycle. These organisms depend directly or indirectly on a steady and enormous supply of nutrients dropped, flushed, and leached out of the terrestrial part of the system. Numerous species of fish and crustaceans that spend their adult lives offshore, and some that migrate and live up the rivers, utilize the mangrove estuaries as breeding and/or nursery grounds. There were early indications of post-war declines in South Vietnam's offshore fishery (involving both true fish and shellfish (crustaceans)) attributed to the wartime spraying.

It is important to note that the mangrove type is a transitional zone between land and sea and thus appears to serve the added important function of stabilizing the shoreline. As the coastline accretes, mangroves invade the virgin lands and their roots hold the soil against the action of wind, wave, current, and tide. The unprotected channel banks and barren mud flats created by the spraying were seen to erode at rapid rates.

With so much of the mangrove habitat destroyed, it was clearly the ecosystem most seriously affected by the Second Indochina War. With the promise of long-term conversion of a significant fraction of this habitat to other vegetational types (whether by natural or anthropogenic means) the question arises to what extent such long-term habitat loss will lead to species extinctions. It is known that the number of species within any particular taxonomic group that an isolated habitat can support is related to its area. If a habitat is reduced in size, as has been the case with South Vietnam's mangroves, the resulting excess of species will in due course die out. It has been estimated by the author that a 10% reduction in this mangrove habitat (a likely situation) will in time lead to a 3 or 4% loss in the indigenous plant and animal species (Westing, 1982a).

Agriculture

During the Second Indochina War the USA carried out a routine military policy of systematic large-scale crop destruction in South Vietnam. Chemical crop destruction from the air made up the greatest fraction of this major resource denial programme. Chemical crop destruction is estimated to have affected some 236 thousand hectares of agricultural lands in South Vietnam one or more times (approx. 8% of the total) (Table 5.6.6). In all, herbicides were sprayed over some 356 thousand hectares of agricultural lands in South Vietnam, although this larger value does not take into account sprayings of the same fields during different years. (At least 8 thousand hectares of crop lands were additionally sprayed elsewhere in Indochina, especially in Laos.) The crop spraying is estimated to have resulted in the immediate destruction of more than 300 million kilograms of food.

Additionally, perhaps 30% of South Vietnam's 135 thousand hectares of rubber plantations were destroyed by herbicides during the war (Westing, 1980).

5.6.4 SOUTH VIETNAM TODAY

5.6.4.1 Herbicidal Persistence

Important in any consideration of the long-term impact of herbicides is their persistence and mobility, that is, how long they will remain present and active in the soil and biota, and whether they will move up in food chains, perhaps even concentrating in the process (so-called ecological amplification). For 2,4-D, representing 48% of the chemicals sprayed (Table 5.6.2), a level of environmental insignificance (as determined by lack of obvious effect on all but the most highly sensitive of subsequently planted test species) is reached within a month or so. For 2,4,5-T, representing 44% of the chemicals sprayed, this occurs within five months or so; for picloram, representing 2% of the chemicals sprayed, within perhaps 18 months; and for dimethyl arsinic acid, representing 6% of the chemicals sprayed, after about a week. Chemical analysis would, of course, reveal traces of all these substances for some time beyond the durations just given, as might the sowing of particularly sensitive indicator species. Some relevant examples from the literature follow.

In Hawaiian field trials, it was found that 2,4-D applied at the rate of 11 kg/ha continues to affect subsequently planted indicator plants such as bean (*Phaseolus*; Leguminosae) or tomato (*Lycopersicon*; Solanaceae) for 2–14 weeks (Akamine, 1950–1951). In Puerto Rican field trials, it was found that a 1:1 mixture of 2,4-D and 2,4,5-T applied at 27 kg/ha exerted a significant residual effect on various herbaceous monocotyledons and dicotyledons for 2 months; and picloram at 7 kg/ha for 3 months (Bovey *et al.*, 1968). In further trials there, the effects of picloram at 3 kg/ha could be detected on cucumber (*Cucumis*; Cucurbitaceae) for 12 months (Bovey *et al.*, 1969).

In South Vietnamese field trials, it was found that when Agent Orange was sprayed onto cleared inland forest soils at military dose levels, such treatment ceased to cause a reduction in survival and growth of, *inter alia*, subsequently planted corn (*Zea*; Gramineae) after 4 weeks, of upland rice (*Oryza*; Gramineae) or peanut (*Arachis*; Leguminosae) after 10 weeks, and of bean (*Phaseolus*; Leguminosae) after 18 weeks. In an equivalent trial with Agent White the intervals to insignificant damage were 10 weeks for both corn and upland rice, 31 weeks for the bean used, and 24 weeks for peanut (although some presumably trivial effects were still discernible on the peanuts for at least 34 weeks, the time at which the observations were terminated) (Blackman *et al.*, 1974).

When either Agent Orange or Agent White was similarly applied to cleared mangrove forest soils, the herbicidal rate of disappearance was reported to be similar to that found in the inland forest soils. Moreover, when seedlings of two common mangroves (*Rhizophora* and *Ceriops*; both Rhizophoraceae) were transplanted into such treated soils 40 days after spraying, their rate of survival appeared to be equivalent to that in control soils.

In temperate-zone field trials with dimethyl arsinic acid, it has been found that for such horticultural operations as lawn renovation, grass can be sown without harm to it immediately following an application of 22 kg/ha since sufficient inactivation occurs during the few days prior to seed germination (Ehman, 1965). It was further reported that subsequently harvested alfalfa (*Medicago*; Leguminosae) and ryegrass (*Lolium*; Gramineae) that had been sown 3 days after pasture treatment at 6 kg/ha contained arsenic levels no higher than in control plants.

The dioxin contaminant of the 2,4,5-T in Agent Orange turned out to be considerably more persistent than its carrier agent. A conservatively estimated total of 170 kg was applied to South Vietnam, primarily during 1966 to 1969 and largely in the former Military Region III (Table 5.6.7). The dioxin, once incorporated into the local ecosystem, can be assumed to disappear from the environment following first-order kinetics and can be calculated to have an environmental half-life of the order of 3.5 years (Westing, 1982a; *see also* Olie, 1984). If one makes the simplifying assumptions that the estimated 170 kg of applied dioxin had all been introduced into the South Vietnamese environment in 1968 and that half of it had become incorporated into the soil and biota (the other half presumably having been rather rapidly photodecomposed), then perhaps 8 kg remained present in 1980, 3 kg in 1985, and 1 kg will presumably be present in 1990. The action of wind and water is likely to have enlarged (and continues to be enlarging) the original area of application of 1.0 million hectares, a matter that is disturbing in the sense that the area of contamination is expanding, but reassuring in the sense that the severity of contamination in any one locality is declining, not only via decomposition but also through scattering.

Table 5.6.7 Dioxin applications in South Vietnam in the Second Indochina War: a rough approximation*. Source: calculated from the data in Tables 5.6.2 and 5.6.5

Year	Military Region I†	Military Region II†	Military Region III†	Military Region IV†	Total
A. Amount (kg)					
1961	?	?	?	?	?
1962	—	—	0.1	—	0.2
1963	0.2	0.2	0.6	0.1	1.1
1964	0.6	0.8	1.9	0.3	3.6
1965	1.2	1.4	3.6	0.6	6.8
1966	4.1	5.1	12.9	2.2	24.4
1967	7.7	9.6	24.1	4.1	45.5
1968	5.8	7.1	18.0	3.1	33.9
1969	8.1	10.0	25.1	4.3	47.4
1970	1.2	1.5	3.7	0.6	6.9
Total	28.9	35.7	90.1	15.3	170.0
B. Amount per unit area, assuming uniform distribution over the entire region (mg/ha)					
1961	?	?	?	?	?
1962	—	—	—	—	—
1963	0.1	—	0.2	—	0.1
1964	0.2	0.1	0.6	0.1	0.2
1965	0.4	0.2	1.2	0.2	0.4
1966	1.5	0.7	4.3	0.6	1.4
1967	2.8	1.2	8.0	1.1	2.6
1968	2.0	0.9	5.9	0.8	2.0
1969	2.9	1.3	8.3	1.1	2.7
1970	0.4	0.2	1.2	0.2	0.4
Total	10.3	4.6	29.8	4.0	9.8

*The estimated 170 kg of dioxin was directly applied to about 1.0 million hectares, that is, onto about 6% of the surface of South Vietnam (Table 5.6.2). Thus the average dose on this directly sprayed land was about 163 mg/ha. About 155 kg, or 91% of the applied dioxin was sprayed onto forest lands and the remaining 15 kg, or 9%, onto agricultural lands (Table 5.6.3)

†The former Military Regions are depicted, and their areas and mid-war populations provided in Figure 5.6.1

5.6.4.2 Long-term Effects on Flora and Fauna

Recent examination of the inland forests of South Vietnam has established that the wartime herbicidal damage of more than a decade ago is still much in evidence. It was reaffirmed that the severity of original damage and progress towards recovery depend on a variety of complex (and often little understood) factors, including: pre-spray condition of the stand; frequency and season of original spraying; species composition; steepness and other features of the terrain: local climate; areal extent of damage; availability of a seed source; and subsequent fire history (see below). It appears that with one or two original sprayings of a dense inland forest, a sufficient number of understorey trees survived that will grow and provide at least a poor harvest in three to four decades following attack (Ashton, 1984). However, it was estimated to take eight to ten decades following such spraying for a stand comparable to the pre-spray one to become established.

Those inland forests sprayed three or more times were generally damaged sufficiently to result in subsequent site damage from soil erosion and nutrient dumping (loss of nutrients in solution) and for the establishment of a grassy cover, usually herbaceous though sometimes woody (Ashton, 1984; Hiêp, 1984a). It turns out that these now herbaceous-grass-dominated sites have been burned over during many of the annual dry seasons since the war, such fires often being of human origin (Galston and Richards, 1984). These repeated fires have not only essentially prevented the re-establishment of trees, but have even been encroaching on the surrounding forest and have thus been slowly expanding in size. The modest natural forest regeneration in these badly damaged areas has been with trees of poor quality. The very important post-war role of fire in impeding forest recovery, and even in exacerbating the original degree of damage, has been the major revelation of the recent inland forest studies.

Herbicidal decimation of a forest leads to site debilitation for a number of reasons. The nutrients released by the fallen foliage cannot be held to any great extent by the soil and are thus lost to that ecosystem. Such nutrient dumping is especially severe in the tropics and often prominently involves potassium, nitrogen, and phosphorus (Zinke, 1984). As the trees die, the newly unprotected soil is subject to erosional loss—the more so the steeper the terrain—until the re-establishment of a new vegetational cover (a grass cover, which, however, protects the soil less well than the former trees). Indeed, recent soil studies have revealed that soils on steep slopes that had been subjected to the wartime spraying are, more than a decade later, still seriously depleted in nitrogen as well as in total organic matter content (Huây and Cu, 1984).

It has become quite clear that, for vegetational recovery to occur in the seriously damaged inland forests, fire must be excluded and, moreover, that the worst damaged areas will require artificial planting. Indeed, site debilitation has in many instances been sufficiently severe to require pre-planting (or inter-planting) with hardy soil-holding and soil-enriching species, for example, with nitrogen-fixing leguminous trees (Ashton, 1984; Galston and Richards, 1984).

The close association between an animal's geographical distribution (i.e. the animal's presence or absence) and its particular habitat requirements is a fundamental tenet of ecology. Indeed, this relationship is an especially tight one in tropical forests (Leighton, 1984). Recent comparisons in South Vietnam of unsprayed inland forest sites with comparable sites that had been multiply sprayed during the war, have been subjected to subsequent fires, and are now dominated by grasses, abundantly confirm this relationship. For example, in two unsprayed forests 145 and 170 bird species were recorded whereas in the destroyed forest (now grassland) there were only 24 (Westing, 1984b). Similar values for mammal species were 30 and 55 in the two unsprayed sites, but only 5 in the comparable though previously sprayed site. Moreover, an examination of the mammalian species that comprise these numbers reveals that whereas most taxa of wildlife declined, the numbers of undesirable rodent species increased.

To ameliorate the disastrous long-term impact of destroyed habitat on wildlife populations will require an accelerated programme of reforestation, the prohibition of game hunting, and restrictions on fuel-wood gathering (Huỳnh *et al.*, 1984). More sophisticated actions are called for as well (Leighton, 1984).

As noted earlier, the one habitat of South Vietnam which had been most seriously disrupted by the wartime herbicidal attacks was mangrove. Roughly 124 thousand hectares of this highly productive ecosystem (i.e. approx. 40% of it) had been utterly devastated. A rough field survey carried out by the author in 1980 indicated the following current situation regarding these 124 thousand hectares (Westing, 1982a): (a) barren patches of 5–50 ha, approx. 5–10%; (b) natural regeneration of *Rhizophora* adjacent to residual stands (a highly desirable outcome) approx. 1%; (c) artificial planting of *Rhizophora* approx. 10%; (d) conversion to rice and other crops, about 5–6%; and (e) natural regeneration of low-growing locally undesirable species of palms, ferns, poor-quality mangrove species, etc., about 75%. Much site damage by sheet erosion and wave action has occurred since the war (Snedaker, 1984). The lack of natural regeneration by the ecologically and economically desirable *Rhizophora* has to a considerable extent resulted from a lack of seed source so that an accelerated programme of artificial planting is indicated (Hiêp, 1984b; Snedaker, 1984). Where mangrove species have become established (whether by natural or artificial means and whether of inferior or superior species) a closed canopy can be expected within a decade or two of the time of establishment, and a harvestable crop of wood (small timbers and firewood) in perhaps four or five decades.

The offshore marine fishery of South Vietnam is known to have declined since the war, but whether this phenomenon finds its roots in the wartime herbicidal attacks, as is suggested from time to time, has not been demonstrated (Snedaker, 1984). However, one recent study indicates that freshwater fish in inland forest areas that had been attacked with herbicides during the war became and have remained substantially reduced both in species numbers and biomass (Yên and Quýnh, 1984). The reduction was attributed to a long-lasting decline within the affected waters of the algae and invertebrates that provide the food for these fish.

5.6.5 CONCLUSION

Faced during the Second Indochina War with a dispersed and elusive enemy in South Vietnam, the USA sought to deny this foe sanctuary, freedom of movement, and a local civilian economy from which to help derive its sustenance. This strategy was pursued, *inter alia*, through an unprecedentedly massive and sustained expenditure of herbicidal chemical warfare agents against the fields and forests of South Vietnam. The use of these agents resulted in large-scale devastation of crops, in widespread immediate damage to the inland and coastal forest ecosystems, and—it might be added—in a variety of health problems among exposed humans.

The damage to nature involved the death of millions of trees and often their ultimate replacement by grasses, in turn maintained to this day by subsequent periodic fires; deep and lasting inroads into the mangrove habitat; widespread site debilitation via soil erosion and loss of nutrients in solution (nutrient dumping); decimation of terrestrial wildlife, primarily via destruction of their habitat; losses in freshwater fish, largely because of reduced availability of food species; and a possible contribution to declines in the offshore fishery.

A vigorous and sustained research effort is warranted in Vietnam in order to pursue and ameliorate the long-term ecological (and medical) effects of the wartime use of the herbicides. The proposed ecological studies should pursue techniques of fire prevention, soil restoration, tree planting (including pre-planting and inter-planting), and wildlife restoration. Study areas and field stations should be established in both inland and coastal habitats. The ecological studies might best be carried out with the active cooperation of such international agencies as the United Nations Educational, Scientific and Cultural Organization (e.g. with its Regional Coastal and Marine Programme).

Finally, the question arises regarding future employment of herbicides as anti-plant chemical warfare agents and of the potentially ecocidal outcome of their use (Westing, 1980). Military evaluations have been favourable as regards a diversity of potential operational theatres (Engineers, 1972). On the other hand, a widely held interpretation of the Geneva Protocol of 1925 makes illegal their use in war (Westing, 1985). Moreover, their impact—especially as demonstrated by the Second Indochina War—makes it illegal to use them in the light of the Environmental Modification Convention of 1977 (Westing, 1984a).

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