Pesticides in the Forest Ecosystem

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Foreword

The dedication of researchers to detail and the daily pressures of the working day often masks or decreases the amenity and/or practical value of intricate individual contributions as related to the primary objectives of major research programs. Certainly, many of us who have specialized input have little occasion to either reflect or philosophize upon individual effort and its "fit" regarding official policy and stated objectives. The increasing demands for safe and effective pesticide treatments in forest management, in my estimation, necessitates a periodic review of individual effort to maintain quality of research as redirection of program occurs. Otherwise, the preoccupation with the tree might forever prevent a view of the forest.

It is with pleasure, then, that we present a seminar paper (ecology) prepared by Miss Joan Allan, second-year biology student at Carleton University, Ottawa. The paper represents Miss Allan's views regarding the difficult and controversial topic of spray treatment in Canada's forests. It also reflects an understanding of the Chemical Control Research Institute's role in forest pest management and the problems of prime importance to the Department of the Environment. Miss Allan's paper offers an opportunity to reevaluate our research expenditures at the same time.

Robert F. DeBoo
C.C.R.I., December, 1974.

Pesticides in the Forest Ecosystem

Preservation of the Canadian forests is often largely justified as an attempt to safeguard an economic interest -- to put guard-rails around an invaluable resource that provides jobs for 300,000 Canadians and furnishes products that comprise nearly 20% of the export dollar (Canadian Forestry Service brochure). However, the forest is fast becoming a recreational facility and aesthetic wealth, and must be maintained for these purposes as well. Man, with all the manipulating ability that advances in technology have given him, is not necessarily subject to the ills that the environment may deal him. He is able to control variables in a way that no other animal can. But where man alters one natural process for his benefit, there ensues a necessity for another alteration, and yet another, to initiate an approach to equilibrium once again.

Of all the hazards to a healthy forest, the forest-fire is the most widely publicized. However, 24% of the timber lost due to catastrophic events between 1900 and 1958 in the United States is attributed to fire, whereas 58% (more than double the value for fire) is accounted for by damage by insects and disease (Graham 1963). An even more contrasting set of values is given by Hepting and Jemison (1958), where fire damage is estimated at 17% of the total loss, and 65% is due to disease and insects.

Insects are a necessary element in the forest ecosystem, and, in fact, are directly involved in the modification of forest composition and succession, by hastening, delaying or altering this process. By their participation in the detritivore food chain they serve both to restore access to the ground for regeneration by clearing away dead wood, and to unbind the chemical elements that are immobilized by plant synthesis. Insects populate a wide range of microhabitats in the forest and exploit a variety of food opportunities. The free atmosphere above and within the canopy exhibit airborne insects in activities of dispersal, pursuit of mates, and search for food and oviposition sites, while the soil houses smaller insects and cocoon and hibernating stages (Graham and Knight 1965).

But, for all the benefits that insects provide by their involvement in the forest community, the injury and death they inflict is monumental, as catastrophic-loss statistics show. Their devastating effects are comprehensively outlined by Graham (1963).

The obvious effects of insect invasion are defoliation and bark-stripping, particularly in specific varieties of trees. This superficial denaturation leads to a consequence of much greater severity. When a tree is the victim of such an assault, it becomes vulnerable to other environmental ills -- possibly mechanical damage, disease or infestation by another species of insects which can take advantage of a weakened condition. Ultimately, the tree dies and the loss is undoubtedly registered in immediate financial terms. That is to say, so many board-feet are lost, or so many dollars. Perhaps the more serious losses are paid to the ecological system. To be sure, the astounding volume of about 2 billion cubic feet of timber is lost annually in Canada

(DeBoo 1970), and this loss must be shouldered by the logging industry at a time when no loss is acceptable, but the forest region itself may be drastically affected.

If one particular variety of trees or plants is removed, the relative balance of competing species is altered. The forest floor is changed by the creation of conditions that are differentially adverse to one species or another. Natural thinning of the understory layer is delayed by removing the overstory shade, and this causes displacement of trees by grass in the transitional areas. Occasionally, succession is hastened by the removal of the pioneer forest species, which allows the statement of a climax forest. More often however, removal of the pioneer species creates area openings which can support only a shade-intolerant breed and thus perpetual regeneration of the pioneer species ensues. One of the most interesting consequences of insect infestation is the forest's susceptibility to fires. Defoliating insects open trees to dessication and leave tinder-dry dead foliage in the crowns. Furthermore, not only is the total leaf or needle complement moved from the tree to the ground to greatly increase the organic layer and thus amplify fire intensity, but the litter layer is then exposed to sun and wind and becomes more flammable. The remaining dead snags act as lightning targets and encourage a fire during the regeneration time. In a denuded area, there is increased water run-off which leads to soil erosion and severe leaching. Some forests design root and branch systems to favour windy conditions, and a loss of these may result in increased wind-throw and blow-down. Lastly, an area that has been ravaged by one type of insect is often subject to an attack by another type which may then migrate to a nearby healthy stand.

Action against this destructive force is requisite for the maintenance of a viable stand. Of the several methods that are available, insecticides provide one of the most effective and versatile means of securing quick and decisive protection from insects, under varied circumstances and on a gigantic scale (Canadian Agricultural Chemicals Association). It is certainly true that insecticides are not appropriate in every occasion, but Dr. DeBoo (1974) assures us that when correctly chosen and properly applied, they can be an excellent control mechanism with maximum effectiveness and negligible detriment to the environment.

Insecticides have been in use for about 25 years, and we might glean from the discouraging publicity concerning these chemicals that they have not been employed correctly. Fettes and Buckner (1972), in analyzing the use and misuse of biocides in the forest, concede the fact that a quarter of a century of experience in this area has "alerted us to the implications of chemical applications to the total forest ecosystem", but go on to say that "undesirable effects are never deliberate and where such effects are discovered, measured and evaluated, they are never repeated" (Fettes and Buckner, 1972, p.1).

The first chemical to be used to any great extent was DDT, a chlorinated hydrocarbon with an estimated half-life of about 25 years (Woodwell et al 1971). DDT was the sole insecticide to be used for the first 15 years of chemical control operations. Initially, it was applied by spraying in the amount of one pound per acre. More for economic reasons than for ecological impact, the amount was reduced to half a pound per acre (1953-1958). Even at this reduced dosage, high mortality of salmon fry and aquatic insects was registered (MacDonald 1967). Consequently, the amount was again reduced, this time to a quarter of a pound per acre, a dosage which was continued into the mid-60's.

A great deal of information can be drawn from the long-term programme of forest insect suppression in New Brunswick. In fact, this case history offers the longest continuum of data available for investigations into DDT activity and that of other major forest insecticides. Eighty-five per cent of the province area is covered with forest, and composed of species (spruce-balsam) that encourage dense populations of Canada's worst insect enemy, the spruce budworm (*Choristoneura fumiferana* Clem.) (Fettes and Buckner 1972). Particular attention will be paid then to investigations into insecticide impact in New Brunswick and similar forest areas in Canada and its broad implications at a world-wide level.

At one time, the forest industry was able to absorb the shock of insect invasion by relocation of their logging sites. However, forested land is currently under such pressure to produce at an optimal level that such infestations and subsequent fires cannot be allowed. In 1951 an insect ravage was predicted in New Brunswick and DDT, the "wonder chemical" was brought into the picture. The theoretical positive effects greatly outnumbered the possible hazards to fish, valuable insects and wildlife. But then data continued to accumulate which corroborated the reports that non-target mortality is an important coincident factor.

Investigations by Yule and Tomlin (1971) into DDT persistence in forest streams that were made prior to, during and two years following the final operational use of DDT in New Brunswick lead us to believe that the amount of pp'DDT increases during aerial application, but subsides quickly after the spraying has ceased. It is understandable that where DDT was applied in an oil suspension, large amounts of DDT occurred on water surfaces in oil slicks. Equally understandable is the finding that surface water contains considerably more DDT than water at a depth of 12-18 inches, immediately after chemical application.

Bioassay work reviewed by MacDonald (1968) averages the lethal level of DDT in water for young salmon at 50 ppb. This information, accompanied by a delay in fish kills seems to indicate that DDT concentration increases over the first few days after spraying. While there is a drop in DDT concentration in water within a few hours after spraying (i.e. below 50 ppb), there is record of particulate matter containing up to 606 ppm in the few days following spraying, followed by a corresponding decline. If these coarse suspended particles include organic food material, and presumably they do, Hopewell's (1962) proposal that fish poisoning is via feeding activities is substantiated. Further in this direction, DDT arrives at the stream through aerial transport of dust and organic debris and by surface run-off (as DDT is bound tightly by forest soils, and thus is less likely to be leached to undergound waterways, than to be washed attached to solid matter into streams).

By the late 1950's, so much negative data had been collected that there was no alternative but to commence the development of a substitute, and by the mid-60's the carbamates and organophosphates were emerging as potential replacements. It must be remembered however that DDT was still in wide use, and during the advancement of an equally effective but less harmful insecticide, it was still effecting major immediate changes in the forest. Phosphamidon, an organophosphate, was tested operationally in 1963 in one-mile blocks along major salmon rivers in New Brunswick, while the remaining area was treated with DDT (Fettes and Buckner 1972, MacDonald 1967). Measurable bird mortality necessitated a decrease in the proportion used of this insecticide to one quarter of a pound per acre. In combination with DDT, this insecticide is very effective against the budworm and is considerably safer and cheaper than other organophosphates.

Control of lepidopterous defoliators in Canadian forests has been largely commanded by fenitrothion since 1969, at the economic dosage of 2-4 ounces per acre, without severe damage to plants or animals (Fettes 1968). This pesticide is registered for forest use only, against the budworm, hemlock looper and sawfly, and though its environmental impact is to a lesser degree than DDT's impact, it is characteristically similar. Further discussion will focus upon results of application of both these chemicals, bearing in mind their levels of effect.

The initial result of spraying is high mortality of both target and non-target species (Fettes and Buckner, 1972), particularly of the flying variety. Graham (1963, p. 255) classifies the entry of the chemical poison into the insect body as one of "contact", tracking or "residual", "stomach" and "systemic". Contact poisons are those applied directly to the integument; residual poisons are those which an insect picks up by walking over a treated surface; stomach poisons enter by ingestion of contaminated food; and systemic poisons are applied to the bark, foliage, etc. of a tree, are absorbed into the tree sap and thus enter the insect system via sap-sucking or chewing. Quite obviously the chemical is chosen with a specific pest in mind --- i.e. species with little body contact with contaminated surfaces will not be greatly affected. Most chemicals bring about disjunction in a variety of ways that reduce insect survival and reproduction. Some chemicals disrupt vital functions or desynchronize their functions in relation to environmental factors, perhaps sensitizing them to these factors as well, or destroying symbionts upon which they depend. (Krehm 1973).

DDT and fenitrothion have been extremely effective in the elimination of insect threat. The unfortunate incidence of high mortality in non-target species gave rise to investigation of spraying effects on parasitic and predaceous insects. If a pest population is reduced below a level that is critical for search efficiency of the attacker, the latter must decline. Thus, by removal of a potential restraint, the opportunity is restored for the pest to again increase. However, less intense destruction of a pest population, even if it kills a proportional number of predators or parasites, may establish a more favourable opportunity for parasites to overtake the host. On the one hand, foliage conservation and predator kills may give rise to higher pest counts than in unsprayed areas, the likelihood of which will be reviewed later, and on the other, poisoning of associated insect fauna may result in mortality counts far smaller than those produced by the parched, defoliated conditions following infestation.

A great deal of work has been carried out concerning the effects of chemical application on pollinating insects, particularly the honeybee (Buckner 1973). The threat to these insects is diminished by the use of bee repellants and the replacement of residual poisons by stomach types (Graham 1963). Analysis of fenitrothion residues in honeybees and their products by Sundaram (1974) gave the retention time to be no greater than ten minutes in any of these forms.

Occasionally, birds are almost immediately affected by insecticide application, exhibiting insecticide tremors and ultimately death. Studies by Buckner (1973) revealed that 2 ounce applications of fenitrothion had little effect on birds in densely foliated habitats, while those species in open areas were more subject to mortality or reproductive failure. Additional work on small mammals and birds showed only behavioural alterations which normalized within a week, and small mammals, by their secretive nature, exempted themselves largely from adverse conditions (Fettes and Buckner 1972). In all cases, populations had equilibriated to former proportions within a matter of days.

Although long-term effects are difficult to state conclusively, a cause and effect relationship between DDE in the diet of birds, particularly the brown pelican, and "eggshell thinning pehnomena" has been established, where up to 15% thinning of the shell is associated with DDE residues of 4-5 ppm. (Blus et al 1972). The amount of DDE in the egg is taken as an index to the concentration of residues in the female, the physiological processes of which determine shell thickness. As brown pelicans are a declining population, and eggshell thinning contributes to population decrease, this pehnomenon is considerably noteworthy. Though the brown pelican is not directly related to the forest system, mathematically similar relationships are associated with other species, though at a level that is species-specific.

Investigations into fish mortalities, similar to those for DDT, were performed in and adjacent to areas sprayed with fenitrothion and it was concluded that no significant mortality amongst the fish populations could be attributed to insecticide application to aquatic systems, though very small numbers of trout were possibly poisoned by concentrations of fenitrothion in surface oil slicks. (Kingsbury 1973).

Although contamination in the atmosphere has been studied less thoroughly than in soil and water, it is known that much of the dosage of pesticides applied by aircraft to land targets can be lost to the atmosphere and will drift locally (Akesson and Yates 1964). One aircraft discharging dust at 300-500 pounds per minute multiplied by the number of aircraft required for large scale application gives a very large dimension for drift potential. To obtain a proper perspective of drift problems, all aspects of the application must be considered--the purpose, the method, the material---bearing in mind that the loss of chemicals by drift is a loss of application efficiency. Certainly, atmospheric transport may account for pesticides being found in air, rain and dust remote from significant application sites. Surveys done in New Brunswick at the time of the 1969 budworm control programme (where approximately 700,000 pounds of fenitrothion were applied to approximately 3 million acres of pulpwood forest in 4 weeks) showed that this large operation contributed relatively small amounts of insecticide to atmospheric contamination, and to other parts of the environment outside the target area. If the amounts of phosphorus collected daily in this survey were attributed to fenitrothion introduction, they would still represent less than the 0.01 mg/kg body weight that might be taken in per human per day. It was concluded then that the local inhabitants were not faced with a health hazard (Yule et al 1971, Yule 1970, Yule and Tomlin 1970).

A similar survey was carried out on the persistence of fenitrothion residues in forest foliage (Yule 1974). Balsam fir was chosen as the indicator species for coniferous trees, and the findings were that although 70-85 per cent of the initial dosage of the insecticide deposited on the trees was lost by the foliage within two weeks, about 10 per cent remained for at least 10 months. Soil analysis showed persistence of residues to be much less than that in foliage ($<$0,02 ppm).

Probably of more ecological effect than those values already discussed, such as mortality figures and pool accumulations, is the resistance induction that is set up. That is to say, insects undergo a selection process which culminates in the evolution of a species type which is resistant to the effects of the particular insecticide. This resistance is quite often generalized to similar chemical compounds and thus the resulting "invulnerability" of insects is distributed over a host of chemicals. According to Dr. DeBoo (personal communication), this creates a considerable problem in control procedures, and makes it necessary to alternate insecticides to prevent such a build up of resistance. Just what will come of this inbred characteristic immunity is still not fully understood (Grant and Brown 1967, Sprague 1968).

Our concentration thus far has been upon the immediate effects (ie. within years of operational use of insecticides) but the persistence of these chemicals, particularly DDT holds grave implications for long-term activity in ecological systems. It has been the experience to date that immediate effects subside relatively quickly to allow some sort of stabilizing of the community, but it is thought that "worldwide effects may be occurring unobserved or masked by other causes" (Woodwell _et al_ 1971, p. 1106). It is perhaps difficult to perceive that of the total amount of DDT applied, only a fraction of the spray lands on the target, while the remainder is left aerially suspended or falls on non-target species as well as soil. Thus, it turns out that the primary reservoirs of this insecticide are the land surface, the troposphere, the mixed layer of the ocean and the abyss (ocean depths). Residues which accumulate in soils may be volatized or carried by run-off and thus be returned to air or water suspension. The total amount of DDT retained by the biota is relatively small when the immensity of these biospheric pools is considered. In fact, the biotic capacity for DDT is so small that appraisal of worldwide movements and persistence become more the focal point.

Perhaps more important than initial mortality counts in the forest ecosystem are the possible consequences that DDT-spraying will have universally. There is a tendency towards amplification of biocidal effects as the trophic ladder is ascended. This is due to the typical concentration effect that is seen from level to level and has come to be known as "magnification" (Woodwell 1967, Odum et al 1969). High concentrations will cause reductions in food webs, elimination of carnivores and the favouring of hardy, small-bodied organisms (Woodwell 1970).

Thus, one effect of DDT is to reduce biota and to increase the rate of removal of residues into sediment. This accentuates the importance of local contamination and entrance into the biotic elements through food webs and direct absorption. It also spotlights the attempts to reach equilibrium after such an intervention, a time interval which is estimated to be "four times the average life-span of the longest-lived species and the sum of the life-spans for all trophic levels" (Harrison et al 1970 p. 504). This time value infers that realization of equilibrium would take decades... and therefore, continued input would postpone such a balance for many years. What we have then is this: small-bodied, warm-blooded carnivores (i.e. birds) that have high metabolic rates and feed from water-based food webs accumulate high concentrations of DDT and experience drastic depletion as a species. Under these circumstances, the concept of an equilibrium becomes elusive -- there is no true equilibrium, only a constant state of flux through a pool that probably grows smaller as the biota is reduced (Woodwell et al 1971).

It can be reasoned then that although the most conspicuous effects on biota have been due to local spraying operations, long-range effects are not only possible, but probable, as seen in DDT content of oceanic birds which have absolutely no direct contact with terrestially-applied DDT except through their feeding activities out at sea (Risebrough et al 1967).

From all this, the very least that we can glean is that pest control is essential, and chemical means, though the most effective to date, may well be a subject for further investigation, particularly in impact areas that are not yet clearly understood. The most recent concern is that chemical intervention may encourage the recurrence of a similar outbreak, long before an outbreak would set in naturally. It is known that operations can, in some cases, prolong the duration of outbreaks, but now it appears that the interval between attacks is shortened by control. Ring-growth studies on old trees have been used to determine the dates of previous outbreaks and have shown that the shortest interval between infestations is thirty years and the longest, one hundred years. However, an interval of only 21 years is recorded between the most recent outbreak in New Brunswick and the Gaspe, and the last one before that.

The goal of the spraying programme was realized by maintaining the forest during the outbreak. However, by this conservation, the natural course of events did not take place. Because the trees did not die, a regeneration time was not necessary, and the forest could support another outbreak much sooner (Blais 1974). Climatic conditions also set the scene for an outbreak, and when both forest conditions and climatic release are coincident, an outbreak can be predicted (MacDonald 1967).

It would be very easy indeed to clutch at this information and immediately jump on the bandwagon for the termination of all chemical control. It would seem that mistake after mistake has been made in insecticide application and that continuation of this or a similar programme can only result in disaster. However, it must be remembered that introducing pesticides into the environment is a controllable device. Unlike industries that pour refuse chemicals into the environment as side-products, insecticides are quite purposefully applied with a very clear goal in mind. It is unfortunate that no previous experience in this line of study is available for an operation of this nature to be based upon, but there is no reliable ground upon which you can make the accusation that such research is done solely by trial and error. It can be seen from the documentation presented here that there is no sure way of knowing initially how much of a chemical is needed to be effective without being detrimental, but information like this has now been, and is continuing to be, established by investigation by such organizations as the Chemical Control Research Institute (Canadian Forestry Service) in Ottawa.

It also remains that, as potentially harmful as pesticides may be, there is no better method of pest control.) It comes down to a question, moral or philosophical as it may be, of what we are trying to save. Can we realistically "bury" the chemicals and return the forests to their natural processes of succumbing to infestations and then taking many years for regeneration, while cutting back our resource of wood and wood-products and making the area an unsightly desolation? Alternatively, can we save the forests only to inflict other environmental components with unknown injuries? It is a difficult question to answer, but it is unlikely that man will turn back time to the point of no intervention at all.

The success of a control programme is evaluated by both its results and its cost. Dr. DeBoo suggests that we are into a time when insecticides, like oil and sugar, are at a premium. He goes on to say that "We've come this far in our research and yet we're faced with the possibility of having to revert to the use of DDT, simply because other chemicals are getting harder and harder to get... We hate to see that happen, but there may be no other way..." (personal communication). Control is in fact limited, not only by budgets, but by the availability of tried-and-true insecticides.

Neatly defined by Geier, pest management "seeks to deal with populations.....for they are biological units in which species exist. A population results from complex and continuing interactions between the innate qualities of a species and the effective attributes of the environment is which the population is both supported and limited numerically. The abundance of a population is a function of the fitness of the innate qualities of individuals in the population for the operative features of the environment... This fitness can be reduced (a) by modifying the innate qualities which enable individuals to perform their life functions within the population and the environment; or (b) by altering essential features of the environment in such a way as to make it no longer able to support large numbers of a population while leaving the innante qualities of its members unchanged. Pest management implies acceptance of continued existence of potentially harmful species, albeit at tolerable levels of abundance". (1966, p. 475).

Clearly, then, pests must be managed. Alternatives to chemical control are now being researched though none of these are capable yet of replacing pesticides (Morris and Armstrong 1973, Hall 1963). Alternatives include several forms of biological control such as viral and bacterial infections, as well as the use of chemosterilants and insect sex attractants.

The main issue remains the manipulation of environmental processes with the maximum benefit to man and the minimum disruption to these processes. Insecticides are a major tool, and what is required now is not panic at the use of this tool up till now, but foresight into future potentials for these chemicals.

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