OFFPRINTS FROM AQUATIC TOXICOLOGY AND WATER QUALITY MANAGEMENT
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PESTICIDES IN FORESTRY AND AGRICULTURE: Effects on Aquatic Habitats

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1. INTRODUCTION

In anything we do there are conflicts and trade-offs to be made. The greater the scale of intensity and extent of the activity, the greater the conflicts and the more difficult the adjustments. With demand for higher production of higher quality foodstuffs, and with demand for forest products approaching and, in New Brunswick, exceeding production growth rates, we can no longer afford to share our crops with pest species; thus, the need for pesticides has increased. It is hardly necessary to tell aquatic toxicologists where the conflicts are.

The contributors to this chapter were chosen for their particular insights into the nature of these conflicts. Perhaps we can clarify the problems, even if we cannot solve them. We might even help to achieve the characteristically Canadian solution—compromise. The contributions represent five perspectives, agriculture, forestry, industry, fisheries, and environment, which follow in that order. The first two, agriculture and forestry, are the activities that are considered to be the principal users of pesticides, even though on an area basis a great deal more pesticides are used in urban areas. From the aquatic perspective, they qualify as villains. The pesticide industry is even less popular with those charged with protecting the aquatic environment, even though they must use its services occasionally. However, pesticide companies in Canada are developing an increased awareness that their products must be environmentally safe as well as efficacious to be acceptable in the marketplace. The fisheries are the victim. Whatever we terrestrials do seems to affect water quality one way or another. Pesticides are not the only chemical products that are of concern to aquatic biologists, but they are designed to kill, so they stand high on the list. Fisheries people have been concerned about a number of insecticides used in forestry, including DDT, aminocarb, and fenitrothion; black fly larvicides such as methoxychlor; and a wide range of insecticides and herbicides used in agriculture.

Finally, environmental people tread a thin line between environmental purity on the one hand, and exploitation of the gifts of chemistry on the other. Trying to be impartial makes them seem pawns of industry and government to the environmentalist, and zealots to the grower who lost the only product that worked because it was banned. They are people caught in the middle, perhaps the most difficult position of all.

2. AGRICULTURAL PESTICIDES IN THE AQUATIC ENVIRONMENT: RISKS AND BENEFITS*

Among agricultural practices, the use of chemicals is a recent phenomenon. Extensive chemical use has occurred for less than 35 years but has significantly changed the face of Canadian agriculture. In the golden years, pesticides were regarded as wonder chemicals allowing unprecedented increases in crop yields, improving food quality and production, giving added protection of human health, and improving human welfare. Pesticides have ameliorated the standard of living and provided increased enjoyment of life through improved recreational activities in areas not previously possible. By the 1960s, however, a downside of pesticide use was becoming well documented: Undesirable effects were reported in the environment; in some applications, the chemicals

*Section 2 was written by J.E. Hollebone.

intended to provide economic benefits were found to be jeopardizing human health. In crop management, use of chemicals has sometimes intensified other pest problems intended to be solved, (e.g., development of pest resistance). Great strides have been made since these early years by regulatory agencies to allow needed pesticide uses but to control unacceptable environmental and human safety effects. There is, however, considerable room for improvement.

This section addresses the general subject of agricultural pesticides in the aquatic environment. The subject could perhaps be more pertinently addressed as a question: Can agricultural pesticides be used safely with no or acceptable impact on the aquatic environment?

The question has several sides to explore:

1. Are agricultural chemicals necessary? If they are not, we probably should not be using them.
2. Do chemicals get into the environment? What are the risks if they get into the environment?
3. Can there be an acceptable balance between use and safety?
4. What should we be doing now and in the future?

2.1. Use of Agricultural Chemicals

There is no doubt that for the near future the use of chemicals as an aid to agricultural production is here to stay. Users of pesticides point to the high quality, variety, and volume of food produced with the aid of pesticides. Although new plant varieties, fertilizers, and management practices have played a role in this increase, credit must go in large part to agricultural chemicals for the control of serious diseases, insect pests, and weeds in crops. In agriculture, it is estimated that in the United States for every one dollar invested in pesticides there is a ten-dollar return. This is an average figure. Estimates differ slightly for different situations and different analysts. Pimentel (1982) arrived at an overall return of $2.82. For Canadian field crops the return is also significant. Recent work by Tolman et al. (1986) found that insect-incurred losses in the absence of pesticides were 47–50% for potatoes, 39% for onions, and 58% for rutabagas. In fact, in onions a commercial crop could not be harvested without the use of pesticides (in particular, herbicides are needed for weed control). Stemeroff and Madder (1985) found that apples could not be produced competitively in the absence of fungicides, although, through Integrated Pest Management programs, insecticide use could be reduced considerably in many years. It is not intended to belabor the benefits of chemicals as crop production tools, but merely to point out that many of the perfect fruits and vegetables available to the Canadian consumer today are there because pesticides have allowed high yields and high-quality crops.

2.2. Do Pesticides Get into the Aquatic Environment, and What Is Their Impact?

Agricultural chemicals have been found in the aquatic environment. They are there, sometimes as a result of direct contamination, most often by movement into water due to careless handling (e.g., from disposal of pesticide containers in ditches), accidental spills, or aerial overspray. Or they can reach water indirectly through volatilization and drift from application equipment on nearby treated fields, by runoff in surface water from fields, or from vertical leaching in internal soil drainage systems to groundwater aquifers and lateral transfer to river systems. Finally, natural factors, such as heavy rain, can result in transport to aquatic systems even of pesticides bound tightly to soil particles.

A recent study by R. Frank (1985) illustrates this point for Ontario. Of 61 pesticides studied in Ontario from 1975 to 1977, 18 (30%) appeared in surface waters because of one or all three reasons listed above. Fifteen came from spills, seven from runoff immediately following application of the pesticides, and four from spills plus runoff. Of the 18 pesticides, 14 were not persistent and four were persistent chemicals; the latter appeared in water all year round. The persistent pesticides, such as atrazine, could be divided into 60% in runoff waters, 20% in internal drainage, and 20% from spills. Once in surface water, many of the pesticides degraded rapidly and could not be detected downstream from the point of application. In the Grand River, only three of the 18 appeared at the mouth in concentrations that could be measured, and all three belonged to the persistent category.

The Ontario situation was chosen simply to demonstrate the point that pesticides do occur in water. Results of a number of other surveys carried out by Agriculture Canada, Environment Canada, and Health and Welfare Canada give additional data.

The second part of the question is not as easy to answer. What is the impact on aquatic systems? It depends, of course, upon a large number of factors, such as the amount and nature of the chemical that gets into the aquatic environment, its persistence, its stability, the nature of partitioning in the aquatic environment, and a host of other physical and biological factors. Most important of all is the effect on aquatic organisms and the ability of the chemical to biomagnify or accumulate in food chains.

2.3. Can There Be Agricultural Use and Environmental Safety?

The answer is equivocal: yes and no. Clearly there are instances where the benefits of use do not outweigh the adverse effects. In Canada, as elsewhere in the world, the group of pesticides identified with the most harmful environmental effects were the persistent organochlorine insecticides. DDT, for instance, has been associated with fish kills, unacceptable residues and longevity in the environment, and bioaccumulation in the food chain, resulting in the well-known effects on predatory birds. As a result, and due to other factors, DDT and other persistent organochlorines, such as aldrin and dieldrin, were deregistered for agricultural uses by the early 1970s.

In other cases, the environmental risks from chemical use may not be perceived to outweigh the possible benefits. In most of these cases the approach taken by regulatory authorities is to try to reduce the risks to acceptable levels by modifying the proposed conditions of use, for example, by specifying use restrictions such as number of applications per season, setbacks, etc. In other cases, decisions may move from the realm of science and objectivity to that of policy and subjectivity. For example, methoxychlor has been used to kill larval black flies in the Athabasca and Saskatchewan rivers for many years. Methoxychlor is known, at the rate used, to have detrimental effects on the aquatic environment. It does not directly kill fish at these concentrations, but residues have been detected at low ppb (parts per billion) concentrations in tissue, and the nonselective kill of invertebrates has been well documented. On the other hand, the unacceptability of the hordes of black flies attacking livestock and humans in the area is also well documented. We have greatly simplified the complexities of this issue. However, the decisions taken have been to allow limited use of methoxychlor to control black flies, yet numbers of treatments have been controlled to reduce environmental impact. Clearly, in this instance the decision has been that limited treatments are necessary to allow livestock production and reasonable human comfort, and that some impact will be tolerated. Meanwhile, however, much effort has gone into exploring alternatives to this broad-spectrum pesticide and recently the biological pesticide *Bacillus thurigiensis israelensis* (*B.t.i.*) has been registered to replace methoxychlor for the majority of treatments. For every decision there are some downsides. While *Bti* has a narrow spectrum of activity and is therefore environmentally much more acceptable, the cost of treatment is higher and the methología of application is still largely experimental and may take some years to perfect.

2.4. What Are We or Should We Be Doing to Allow Use of Agricultural Pesticides, Yet Ensure Safety to Aquatic Systems?

First, we must do the best we can to assess the potential of new chemicals for adverse aquatic impact before they are registered for use. In Canada, pesticides are registered after a presale assessment of their safety under the Pest Control Products Act administered by Agriculture Canada. The review process is a consultative one with other federal departments. Health and Welfare Canada advises on human safety with regard to user and bystander exposure, and sets limits for residues allowed in foods. Fisheries and Oceans Canada and Environment Canada provide advice on the fate of pesticides in the environment and an assessment of possible effects in aquatic systems. In recent years the environmental component of the review process has been greatly strengthened.

Draft Environmental Fate Guidelines have been available since 1982. A revised and updated version is scheduled to be complete by summer 1987. It contains a new section on aquatic fate assessment. The guidelines formalize what has been required for several years, and provide guidance on acceptable protocols. The studies resulting from these guidelines should allow an understanding of what impact a new pesticide will have in the environment. The field of aquatic fate has changed rapidly in the last few years and the new aquatic section is designed to allow better prediction of the fate of a new pesticide in water. Knowing this, plus the inherent toxicity of a pesticide to aquatic organisms, regulators can better decide whether a new candidate pesticide can be used safely and, if it cannot, determine if conditions can be established that would reduce impact to acceptable levels.

Modern analytical chemistry is such that today we can measure concentrations in parts per billion or parts per trillion. This increased sensitivity means that there are very few "perfect" pesticides and that, increasingly, regulators will be assessing benefits of use against risks. The final regulatory position will represent a balanced compromise somewhere between sometimes conflicting needs or points of view.

The synthetic pyrethroid insecticides illustrate the regulatory assessment that is taken in such cases:

1. On the one hand, the pyrethroids are highly effective compounds, with a wide margin of safety to plants, mammals, and birds. They are seen by the farmer as very attractive alternatives to currently registered, more toxic pesticides. In most cases they can be applied without the need for special safety equipment, such as respirators.

2. On the other hand, they are highly toxic to aquatic insects and fish, within the parts per billion range (10^{-9}) to fish and parts per trillion range (10^{-12}) to some aquatic invertebrates. Yet, the synthetic pyrethroids are lipophilic and not particularly mobile. In other words, they do not leach, but are highly adsorptive to soil particles. The argument was made that they would be unlikely to reach aquatic systems if not directly applied to water. No, said the environmental advisors, catastrophic rain events could physically move bound pyrethroids to water where they could dissociate and cause toxicity. Furthermore, direct overspray at operational rates, or spray drift, might cause adverse effects that would be unacceptable, especially in areas considered to be fisheries-productive, such as the salmon streams of British Columbia and New Brunswick, or environmentally sensitive, such as the prairie pothole region of Saskatchewan.

Our approach was to examine drift study data from a number of areas to see if adverse effects could be minimized. We reviewed Environment Canada analyses of research permits in British Columbia that suggested drift beyond 67 m from standard agricultural aerial applications was less than 1%. Then we looked at a pyrethroid study by Ontario Environment, which supported the Environment Canada analysis. Finally, we looked at some data from registrants of these compounds on drift during normal agricultural use.

With the agreement of environmental advisors, a 15-m buffer zone was set for ground-applied pyrethroids and a 100-m buffer zone for aerial application was established around environmentally sensitive areas. Acceptable pyrethroids were registered under temporary registration status, while confirmatory field tests were carried out. In 1985, summer monitoring by Agriculture Canada confirmed that the buffer zones appear to be adequate. Trace amounts, ppt (10^{-12}) concentrations, were found in one prairie slough and low concentrations at a stream mouth adjacent to treated potato fields were reported in an Environment Canada study. The 1985 work was considered preliminary. Further studies were carried out in 1986, again by Agriculture Canada, by Environment Canada, and by the registrants. We do not yet have the results of these studies, but when complete, we hope they will tell us whether an adequate margin of safety has been provided, that is, whether the registrations may continue and farmers will be allowed to use the pyrethroids.

In addition to assessing the aquatic impacts of new chemicals before registration, we try to ensure that pesticides currently registered are being used safely. Fifteen percent of the pesticides detected in water resulted from spills through accidents in handling. One of the most important directions is to raise awareness that pesticides must be used safely. In response to ever increasing queries about pesticides, a Canadian national pesticide call line has been established. The professional staff handled 3271 calls from January to October concerning all aspects of pesticides. Farmer and grower calls accounted for 10% of the enquiries, provincial and extension calls about 30%, and miscellaneous inquiries from such as home gardeners, householders, and environmentally concerned persons accounted for the rest. Also an annual letter is sent to all farmers in Canada to provide advice regarding safe use and handling procedures. Provincial governments have active education programs often associated with licensing. Fisheries and Oceans has produced a cautionary brochure about toxicity of synthetic pyrethroids, and there has been an industry–government filmstrip on container handling and disposal. We see farmer education as being one of our most important means to minimize misuse of pesticides.

Third, we advocate increased monitoring and reevaluation of older chemicals. We do not know the effects of many of the older chemicals in aquatic systems, especially their sublethal effects. A priority scheme for aquatic monitoring has been developed, and a recent pilot study of 684 samples of organophosphates and carbamates in October 1986 found no trace of these compounds in drinking water. Current efforts are underway to coordinate this program with Environment Canada efforts and with the national drinking water monitoring program carried out by the federal and provincial ministries of health.

There are other measures that also can be taken to minimize aquatic impacts. It is not prudent to let pests waste a large proportion of our food. To compete effectively in world and domestic markets, Canadian farmers will be using pesticides. On the other hand, it is not prudent to pollute our environment and it is clear that common sense must be used in the handling of economic poisons.

Agriculture Canada is actively seeking viable alternatives. For instance, there are new thrusts in insect pest management (IPM) endeavors to actively achieve control effectively with less use of pesticides. "Towards an IPM Strategy" (Agriculture Canada, 1986) records a national discussion of the problems, concerns, and research needed to improve effort in this area.

There is a renewed effort toward use of biocontrol organisms to replace, or augment existing chemical control measures. There are risks in this approach, such as the possibility of gypsy moth-like escapes. We must move cautiously in this area. There are also new trends toward use of microbial pesticides and genetically engineered organisms and plants. For these we will need to develop new regulatory guidelines to cover such concerns as their release and fate in the environment.

2.5. Future Regulation

The use of chemicals in the environment will continue to be controversial. By virtue of our increased ability to measure minute deposits and concentrations and increased understanding of cellular processes, the chances of a pesticide without some negative effects in today's world are small. We are becoming increasingly aware of areas where science does not always provide clear directions. We must move from emotional pesticide debate to better cooperation and understanding. We must avoid the polarized positions of pro-agricultural users and those against any pesticide use. There is a need to move toward working more cooperatively to identify and resolve problems and explain solutions, rather than to take rigid accusatory positions on each side. The result will be a more cooperative process in which the interests of one group will be weighed and considered against the interests of another. The solution, which may not be perfect, and may not satisfy everybody, must allow respect for opposing points of view and lead to negotiated settlements. The end product will be a science-driven and balanced decision, which should best protect the interests of Canadians.

3. RISKS TO AQUATIC ORGANISMS FROM FORESTRY PESTICIDE USE IN CANADA*

The effects of forest spray programs on aquatic organisms have been a lively topic of debate for a long time in Canada. Since the time Rachel Carson's classic book *Silent Spring* was published (1962), the effects of forest pesticide use on fisheries resources has generated lively and sometimes heated public and scientific controversy. The effects of DDT used for spruce budworm

*Section 3 was written by P.D. Kingsbury.

control on Atlantic salmon, documented by researchers of the Fisheries Research Board of Canada, constitutes one of the classic examples of the discovery that pesticides are a two-edged sword capable of serious harm as well as substantial benefits. The more recent avalanche of other significant environmental pollution issues, such as acid rain, PCBs, and heavy metals, has caused attention to shift away from forest pesticide use to other environmental issues, particularly as it involves scientific scrutiny and public concern. But the legacy of the serious impacts of DDT still seems to haunt forest managers through the public perception of the risks that current forest pesticide use poses to aquatic organisms. We would like to briefly focus on that risk and attempt to show why such a perception is both outdated and scientifically unfounded.

3.1. Current Forest Pesticide Use

3.3.1. Use of Chemical Pesticides

We must first deal with current pesticide use in forestry and the materials that are being used. There have been some significant changes. First, forestry is a small user of pesticides in Canada (Table 16.1). Forestry use of herbicides, insecticides, and fungicides represents about 1.5% of total pesticide use in Canada, and is not only modest in comparison to agricultural and industrial use, but is also considerably smaller than home and garden use.

There have been some significant trends in forestry, particularly recently, toward less overall use of insecticides, and greater use of less hazardous materials, applied in what we might broadly describe as a more controlled fashion. We have moved away from the organochlorine compounds, DDT in particular, toward organophosphorous and carbamate compounds (Table 16.2). Since the 1970s there has been a substantial decline in the area of eastern Canada sprayed each year to control the spruce budworm, by far the most destructive forest insect pest in the region. Although this is partly in response to the size and intensity of the pest outbreak, there are other factors involved that represent significant changes in policy and practice in forestry.

Table 16.1 Summary of Annual Pesticide Use in Canada, 1977–1982

Use	Amount (kg)	%
Canada—all uses	34,648,000	100.00
Agricultural, industrial, and structural pest control	31,840,000	91.90
Home and garden	2,280,000	6.60
Forestry	504,000	1.43

Source: J.F. Henigman and P.J. Humphreys, British Columbia Ministry of Forests, Protection Branch, Victoria, B.C., personal communication, 1986.

Table 16.2 Operational Use of Insecticides to Control Spruce Budworm in Eastern Canada, 1965–1986[a]

		1000s of Hectares Sprayed[b]					
Insecticide	Period Used	65–69	70–74	75–79	80–84	85	86
DDT	1944–1969	1800	—	—	—	—	—
Phosphamidon	1963–1977	750	2,550	3,950	—	—	—
Fenitrothion	1967–1986	1400	12,800	13,900	7900	352	222
Aminocarb	1970–1986	—	650	8,500	4100	455	197
Bt	1974–1986	—	5	40	520	644	336
Hectares sprayed/yr		790	3,201	5,278	2504	1451	755

[a]Approximate figures compiled from Forest Pest Control Forum reports.
[b]Much of the area sprayed received a second application of the same material.

As forest insect control operations moved away from the use of DDT and phosphamidon, they moved toward materials that are applied in smaller quantities. DDT was generally used at 280 to 1120 g/ha, but fenitrothion is used at 210 or 280 g and aminocarb at 70 to 95 g of active ingredient per hectare, so that even if the toxicities of these materials to aquatic organisms were similar there would be less exposure simply because smaller amounts are used.

Another change is less use of large aircraft on large blocks. This was the type of operation that was relatively common in the early 1970s, in an attempt to suppress insect damage over large areas. Since that time, almost all jurisdictions have deliberately moved away from large aircraft toward smaller aircraft, spraying smaller blocks of forest. One of the main reasons is that there has been a great need to increase the economic and social justification for spraying in terms of what values are to be protected and what the benefit/cost will be. It is expensive to spray large areas of forest.

Almost all jurisdictions have had to use economic analysis to defend, on a long-term basis, that an area has a wood supply critical to the maintenance of an existing industry, and that there will be an economic return on the control operation. All this is part of the current revolution in Canadian forestry which is to get away from forest exploitation and into intensive forest management. The result is a trend toward more intensive use of a smaller portion of the land base. This is particularly true for herbicide use because any site treated with herbicide usually receives other kinds of silvicultural treatments, such as site preparation and planting. All forest herbicide treatments are expensive because the return on investment comes 50 to 80 years later. Herbicides and their application are expensive, so economic justification is needed before money is spent to treat a site.

Table 16.3 Operational Use of Forest Insecticides in Eastern Canada in Recent Years[a]

	1000s of Hectares Sprayed[b]			
Insecticide	1983	1984	1985	1986
Spruce Budworm Spraying Only				
Bt	64 (2%)	376 (19%)	644 (44%)	336 (44%)
Fenitrothion	1553 (56%)	687 (34%)	352 (24%)	222 (29%)
Aminocarb	1162 (42%)	930 (47%)	455 (31%)	197 (26%)
Total	2779	1993	1451	755
All major forest insect pests (spruce & jack pine budworms, gypsy moth, hemlock looper)				
Bt	64 (2%)	376 (19%)	868 (48%)	906 (64%)
Fenitrothion	1553 (56%)	687 (34%)	475 (26%)	301 (21%)
Aminocarb	1162 (42%)	930 (47%)	455 (25%)	197 (14%)
Total	2779	1993	1798	1404

[a] Approximate figures compiled from Forest Pest Control Forum reports.
[b] Much of the area sprayed received a second application of the same material.

3.1.2. Use of Bacillus thuringiensis

For many years the Canadian Forestry Service has carried out research on controlling lepidopterous forest pests with the bacterial pathogen *Bacillus thuringiensis* (*Bt*). Recently there has been a dramatic increase in the use of *Bt* in forestry, both in spruce budworm control and in other insect control programs (Table 16.3). *Bt* was used on only 2% of the area sprayed in 1983; in 1986, 64% of all forest insecticide spraying was based on *Bt* in various commercial preparations. In many jurisdictions, this has been an intentional move and one that is apparently not reversible. It is now policy in the provinces of Nova Scotia and Quebec that *Bt* will be the only acceptable choice for control of insects such as spruce budworm. It is virtually an established practice in other jurisdictions such as Ontario and British Columbia that *Bt* is the only insecticide that politicians are prepared to allow for forest spraying. *Bt* has become and will probably remain the major forest insecticide for those pests against which it is effective. There are obvious benefits in terms of lessened risks to aquatic systems associated with increased used of this highly specific pest control product as an alternative to broad-spectrum chemical insecticides.

3.2. Toxicity and Exposure to Forest Insecticides

A large number of insecticides have been considered and experimented with for forestry use in Canada. Their toxicities to a selection of aquatic organisms

Table 16.4 Toxicity (mg/L), IU/L for *Bt* of Some Forestry Insecticides to Aquatic Organisms[a]

Insecticide	*Daphnia*	Amphipods	Stonefly nymphs	Rainbow trout
Acephate	—	>50	10–12	1100
Aminocarb	0.02[b]	0.01	1.0[b c]	13.5
Bt	—	—	>430 IU/mL[d]	300–1000[e]
Carbaryl	0.006	0.02	0.002–0.005	2.0
DDT	0.005	0.001	0.001–0.007	0.009
Diflubenzuron	0.02	0.03	>2.4[f]	240
Fenitrothion	0.01	0.003	0.004	2.4
Mexacarbate	0.01	0.4	0.01	12.0
Permethrin	0.001	0.001[g]	0.002[c]	0.002[h]
Phosphamidon	0.01	0.01	1.5	7.8
Trichlorfon	0.0002	0.04	0.01–0.04	1.8

[a] 48-h EC_{50} values for *Daphnia* and 96-h LC_{50} values for other organisms except where noted. Data from Johnson and Finley (1980) except where noted.

[b] Holmes and Kingsbury (1980).

[c] 48-h LC_{50} after 1-h exposure (Poirier, 1986).

[d] Eidt (1985).

[e] NRCC (1976).

[f] 14-d EC_{50} after 1-h exposure (Poirier and Surgeoner, 1987).

[g] 24-h $LC_{90\text{-}95}$ after 1-h exposure.

[h] NRCC (1986).

are given in Table 16.4. Of these materials, only fenitrothion, aminocarb, and *Bt* have been used to a significant extent in operational spray programs in the 1980s.

Most of these materials have 96-h LC_{50}'s to rainbow trout under static conditions in the parts per million range. Two exceptions are DDT and the synthetic pyrethroid, permethrin, which are toxic to trout in the parts per billions range 10^{-9}. Not surprisingly, given that we are dealing with insecticides, toxicities to insects and crustaceans are considerably higher than to trout. If we compare these exposures with those that we usually document in forestry situations we see some interesting differences. An extensive study published recently by Morin et al. (1986) summarized peak residues of aminocarb and fenitrothion found in forests, streams, and lakes after spruce budworm sprays in Quebec over a 4-year period. It was based on over 400 water samples collected from various spray blocks immediately after spraying. The median peak concentrations of fenitrothion measured in forest streams were just less than 3 ppb. In terms of the toxicity to fish, these median peak concentrations are one eight hundredth the 96-h LC_{50} value for rainbow trout (Table 16.4). For aminocarb those peak concentrations were less than 1 ppb. The maximum concentrations of fenitrothion found in streams were 127 ppb, a twentieth of concentrations toxic to rainbow trout; for aminocarb they were about 20 ppb. Permethrin, which has a very high toxicity to rainbow trout, has not been used operationally in forestry but the peak concentration found in over a dozen streams directly oversprayed in experimental situations was 2.5 ppb or very close to the concentration toxic to fish.

Peak concentrations refer to the maximum observed pesticide residues in water. These peaks are of short duration in forest streams because there is rapid dissipation and decline in pesticide concentrations once direct spray inputs cease (Fig. 16.1). This is not simply chemical breakdown, but primarily transport and dilution of the material within the type of flowing water systems that we think of as salmonid habitat. Within the first 96 h, the period that we usually use for expressing toxicities, the peak concentration is present for only a short period, declining rapidly so that for most of the 96 h, exposure is to much lower concentrations. Bioassays for 96 h in the laboratory with typical peak concentrations reported in the field expose the fish to a much higher concentrations reported in the field expose the fish to a much higher concentration than that to which they would be exposed in the natural environment. When brief pulses of insecticide are used in bioassays, toxic effects are not seen at concentrations much higher than those producing toxic effects in static bioassays with 96-h exposure.

Some chemical insecticides do pose a hazard to some aquatic invertebrate groups at exposures encountered after normal spray operations. An extensive literature, reviewed by Bart and Hunter (1978) and Trial (1986), suggests that

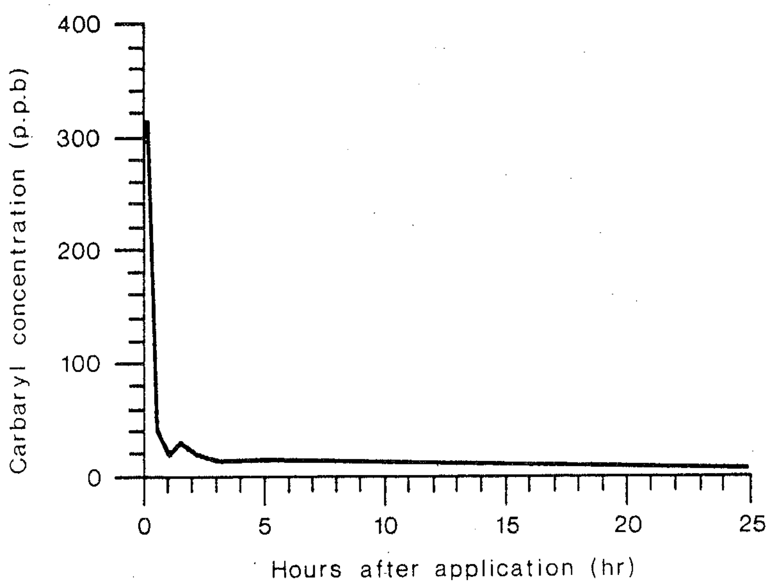

Figure 16.1. Carbaryl residues in stream water following an aerial application of 280 g/ha Sevin-2-oil (after Holmes et al., 1981).

Table 16.5 Toxicity (mg/L) of Some Forestry Herbicides to Aquatic Organisms[a]

Herbicide	*Daphnia*	Amphipods	Shrimp	Stonefly Nymphs	Rainbow Trout
2,4-D					
2,4-D amine	4.0	100.0	0.15	—	100.0
2,4-D ester	1.2	2.9	0.4	2.4	1.0
2,4-D butyric acid	—	—	—	15.0	2.0
Glyphosate					
Glyphosate technical	780.0	—	—	—	130.0
Roundup	5.3	43.0	—	—	8.3
Hexazinone					
Velpar	152.0	—	56.0	—	320.0
Triclopyr					
Triclopyr technical	133.0	—	—	—	117.0
Garlon 3A (Triclopyr amine)	—	—	895.0	—	240.0
Garlon 4 (Triclopyr ester)	10.1	—	—	—	0.74

[a] 48-h EC_{50} values for *Daphnia* and 96-h LC_{50} values for other organisms. Data from Johnson and Finley (1980), Ghassemi et al. (1981), and Weed Science Society of America (1983).

disturbances to stream and pond invertebrate communities often occur with permethrin, carbaryl, and to a lesser extent fenitrothion, although mortality is only partial and recovery occurs within the season of application. There have been cases of more complete and longer lasting impacts of permethrin and carbaryl on the most sensitive invertebrate groups. Aminocarb and *Bt* have little effect on stream invertebrates. Symons (1977) reviewed the literature to 1976, which give data on stream invertebrate drift increases and benthos reductions after fenitrothion sprays, and he concluded that the median response to applications of 210 to 280 g/ha is a 5 to 10% reduction of aquatic invertebrates. In many instances, no effects were noted, and in other cases substantial drift increases and benthos reductions were noted for the most sensitive species, generally mayfly and stonefly nymphs. This reflects variability in spray deposits, protection by overhead forest canopy, and other factors.

3.3. Toxicity and Exposure to Forest Herbicides

The toxicities of the major forest herbicides to fish, as with insecticides, tend to be in the parts per million range (Table 16.5). Herbicides, however, are far less toxic to insects and crustaceans than are insecticides, so that in many cases fish tend to be among the most sensitive organisms on which we have data.

Herbicides enter the aquatic environment by direct application, spray drift, mobilization in ephemeral stream channels, overland flow, and leaching. The relative size of the peak concentration and duration of entry depends on the mechanism, as summarized by Norris (1982):

Entry Mechanism	Relative Size of Peak Concentration	Duration of Entry
Direct	High	Short (during application)
Drift	Moderately High	Short (during application)
Ephemeral channels	Moderate to low	Short (first storms)
Overland flow	Low	Medium
Leaching	Very low	Long

From Norris (1982).

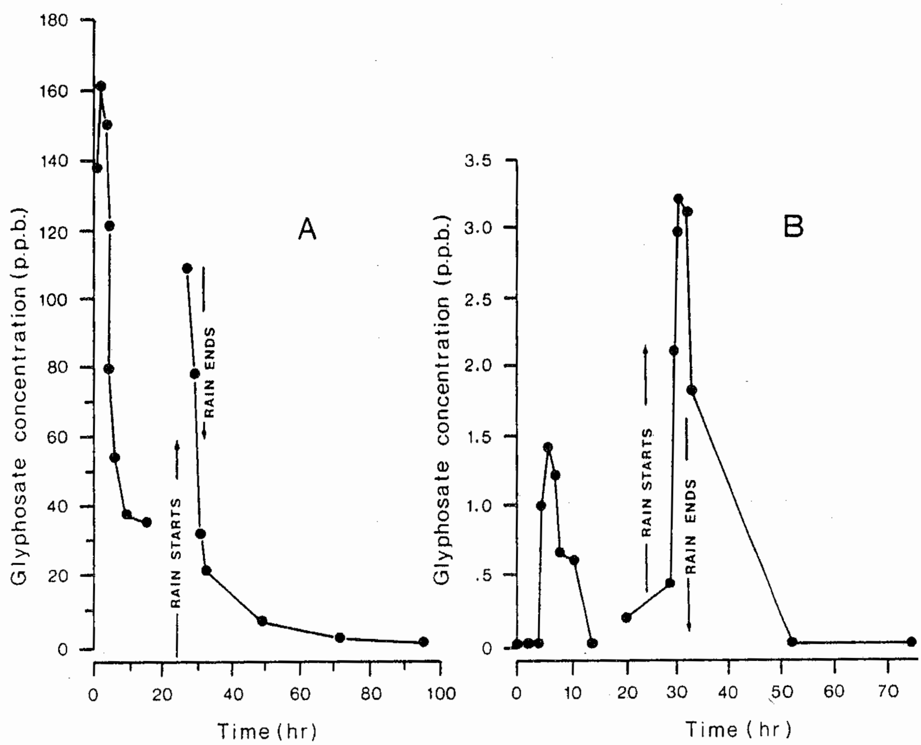

Figure 16.2. Glyphosate resides in stream waters from (A) an experimentally oversprayed tributary and (B) a main channel protected by a 10-m unsprayed buffer zone in a coastal British Columbia watershed (after Feng et al., 1986).

Direct application is the mechanism most likely to introduce significant quantities of herbicide into surface waters and has the potential to produce the highest concentrations.

Herbicides are generally applied at substantially higher rates than are insecticides. In streams, the same type of rapid decline from the initial peaks tends to occur (Fig. 16.2). With herbicides much material is sprayed onto foliage and the forest floor, and when heavy rainfall occurs shortly after application, additional herbicide can enter the aquatic system (Fig. 16.2). Again, this second peak tends to decline rapidly. The peak herbicide residues measured in stream water after forest applications vary with the nature of site, application conditions, and the timing and intensity of subsequent rainfall. Even when streams are directly oversprayed, short-lived peak concentrations in stream water are generally less than 100 ppb, although values approaching 1 ppm are occasionally found (Ghassemi et al., 1981; Norris et al., 1983).

3.4. Buffer Zones and Protective Regulations

Buffer zones are a fact of life in forest spraying. One of the reasons is that aerial application of pesticides to forests falls in the restricted category according to federal legislation. This means that there is a requirement for provincial agencies to grant permits for each application. Provincial regulations are generally accompanied by site inspection by regulatory agencies and their advisors and often by additional stipulation of buffer zone constraints and measures that will limit hazard to aquatic systems. All jurisdictions across Canada have now established buffer zones that are applied to use of pesticides in forestry. They also have regional and local enforcement officers, and because of the high profile of forest pesticide use, enforcement is strict.

Can buffer zones work? There is much research being done on the subject. An example is a recent study by the Forest Pest Management Institute designed to rationalize buffer zones relevant to pyrethroid use (Payne et al., 1986). A number of wading pools containing sensitive test animals were placed at various distances from a permethrin spray line. The data produced (Table 16.6) show that mortality can decrease substantially at distances downwind.

Because of strict control of forest herbicide applications, the herbicides are usually applied to small sites, often from the ground or with helicopters. The data in Fig. 16.2B were generated with sophisticated low-drift application equipment, a microfoil boom, and a 10-m buffer zone. Using such tactics, the peak residue was only a few parts per billion, whereas the peak residue in an intentionally unbuffered tributary (Fig. 16.2A) was about 150 ppb. This occurred despite the fact that the buffered sampling station was in the main stream and received some residue from the small tributary that was intentionally oversprayed.

Table 16.6 Mortality in Populations of *Aedes aegypti* Exposed in Artificial Pools (depth about 7 cm) during Ground and Aerial Applications

	Mortality (%)			
	Ground (35 g of a.i./ha)		Aerial (140 g of a.i./ha)	
Downwind Distance (m)	Predicted	Observed	Predicted	Observed
30	3	2.1	—	—
50	1.2	0.9	39	20
100	<1	1.2	19	2.2
200	<1	0.1	7	0.5
400	—	—	2	0.5

Source: Data from Payne et al. (1986).

Not only are buffer zone restrictions applied to forest pesticide applications, but in some provinces an applicator must have special training before he may apply pesticides to forests. In Ontario, for example, to bid on a contract to apply pesticide to Ontario Crown Land an applicator must have a certain amount of experience in flying in forest situations. The only way he can acquire that experience is to fly under the guidance or direction of an experienced applicator. He must also attend training sessions, including lectures on environmental protection. He is told that if protected waters are sprayed, hazards are greatly increased and furthermore he increases the risk of putting himself and forestry out of business. This is backed up by requirements for performance bonds and liability insurance. The training is taken very seriously and the cavalier attitude that has previously been associated with some pesticide applicators is rapidly becoming a thing of the past. This is particularly true in forestry, where the number of parties involved in and paying for the control operations is small, and those who behave badly soon find no customers for their business.

3.5. Conclusion

There have been extensive studies of the effects on aquatic systems from pesticides that are being used in forestry. Fenitrothion is perhaps the most studied. It was intensively studied by Fisheries Research Board of Canada (now Fisheries and Oceans Canada) researchers at the time that it was introduced as a replacement for DDT. The conclusion of these and other researchers was that the impacts of fenitrothion, as it was used in spruce budworm control at the time, were few and erratically distributed. There was no evidence of direct effects on fish. Sometimes there were increases in stream invertebrate drift and occasionally decreases in benthic invertebrates, but these were sporadic and depended on the nature of the system and the type of exposure. It was felt that not only could these impacts be tolerated but secondary effects on fish were improbable, and given the amount of research that had been done, there was no point to further study the aquatic impacts of fenitrothion under conventional use patterns unless the material or its formulations were made more hazardous. The other two insecticides, aminocarb and *Bacillus thuringiensis*, subsequently introduced and widely used for forest insect control, are even less likely to have impacts on aquatic organisms. Insecticides such as permethrin, which cause dramatic increases in stream invertebrate drift and reduce populations of fish food organisms whenever they are directly introduced into aquatic systems, are not suitable for widespread use in forestry, even though they are still unlikely to cause direct fish mortality. They should only be used in situations where other adequate alternatives for pest control are not available and scientifically established buffer zone requirements have been defined and implemented to protect adjacent water bodies. Forest herbicide use following appropriate buffer zone requirements will have little or no adverse effect on aquatic organisms. The small-scale and controlled nature of herbicide operations and low toxicity and mobility of the herbicides used all contribute to limiting possible effects.

Finally, it should be stressed that forests and aquatic systems are integrally linked. The nature of the forest influences the water quality and yield of the water systems that flow through it (Hynes, 1975). We must manage our forests to maintain the quality of fish habitat. Allowing forest pests like the spruce budworm to ravage extensive forests is not a good way to do it. Drastic changes in cover resulting from tree mortality and salvage logging can drastically alter the stream habitat. For the aquatic environment, the forest's illness left unchecked can be worse than the control measures.

4. THE ROLE OF THE PESTICIDE INDUSTRY IN SAFE PESTICIDE USE*

In tight economic times such as these, it is difficult to formulate a strategy for crop production. Obviously, production efficiency is a paramount concern. Production must be maximized per unit area while minimizing financial drain. This is not merely a matter of controlling input costs but is also a matter of reducing avoidable losses of crop quantity and quality. The only real strategy is intensive management of agricultural and forest resources.

Pesticides are only one small part of the total weaponry available to the producer. How critical to production success are they? Are the needs important or overstated?

The period between detection of a major problem and the time for action is short. Usually no advance warning is available. With literally hundreds of thousands of dollars tied up in equipment, fertilizers, time and seed one must protect that investment. Biological control agents tend to be slow acting. They

*This section was written by M.C. Gadsby.

often require a willingness to maintain low levels of both the pest and the control agent throughout the production period. This is usually not possible. Although very useful, biological control is not the approach for many pest-control situations. Even *Bacillus thuringiensis* and other "bioinsecticides" are not always solutions to critical pest problems. Swifter methods of biological control and biotechnology are still in the future. At present there is little alternative to the use of chemical pesticides.

Pest monitoring reduces the guesswork involved in the timing of pest-control operations. It often makes the difference between effectively treating a real problem and wasting money. Valuable as pest-monitoring is, it cannot by itself control a pest problem, however.

Agriculture and forestry need not be destined to eternal conflict with environmental preservationists. Pesticide use in agriculture and forestry does not guarantee the destruction of sensitive environments. The "Pesticides versus the Environment" issue is not one of irreconcilable conflict. Instead, it is an issue of "essential tension," tension that can fuel "creative compromise." There can be a balance between the benefit from pesticide use and the risk of potential hazard to the environment.

The toxic effects of pesticides must be controlled; there are three basic approaches. The first is applied during pesticide development. Chemicals selected for development are those with toxic effects controlled by the mode of action of the substance, by the method of application, by the timing of application, and by a myriad of other factors. The value of research during the development stage is that it is assessed unemotionally based on the product's performance relative to the projected production costs and market demand. Uncontrollable chemicals are discarded; only reliable, controllable pesticides proceed to market.

The second approach is control of pesticides by legislation; legislation which is determined objectively, based on the real need for pesticides balanced against the potential hazard they represent. Regulations and guidelines based on legislation are established to control uses, dosages, setbacks, waste disposal, and so on, in the same objective way.

Finally, control is exercised over toxic effects of pesticides by careful practices based on responsible guidelines for product use. The decision to use a particular product is objectively made, based on the benefits to the crop, weighed against cost and hazards.

Objective decisions must be based on facts elucidated through competent research. The research must not be a single-minded search for pesticide effect, but a comprehensive look at pesticide behavior. One should ask what normal use patterns pose a real hazard to sensitive environments, how can the chances of pesticide disruption of sensitive aquatic environments be minimized, and how can pesticide effects be mitigated.

These are challenging research questions for which answers will not come easily. Enormous resources are required to respond, and these are not questions that industry or government alone can answer. The real environmental issues can only be elucidated if we work together, using our separate areas of expertise. Any other approach is not realistic or productive. Industry needs access to the experience and knowledge of competent environmental assessors. Environmental scientists need access to agriculture's and forestry's experience in application science, and industry's experience with pure chemistry and goal-oriented research. Together, our expertise is impressive. At present the system is often adversarial, but it need not be. The Canadian system of pesticide registration is one of the best in the world. When adversarial, it works, but cooperatively, it could work a lot better.

5. SELECTED CASE HISTORIES: EFFECTS OF PESTICIDES ON AQUATIC HABITATS*

In terms of the protection of fish and fish habitat, it does not matter whether we discuss pesticides, heavy metals, or other toxic chemicals, since they all represent chemical inputs with which the fish must cope. There is nothing new in this: History and archeology reveal that the release of chemicals into the environment has been with us throughout our cultural existence. What is new is the unprecedented scale with which we can now produce and disseminate chemicals. With ever-growing numbers of people and ever-growing ingenuity in finding new chemicals and new uses of chemicals, there is accelerating growth in the quantities and kinds of chemicals in circulation. Pesticides are just the tip of a chemical iceberg, but pesticides are the only chemicals released into the environment with the deliberate intent of producing biological injury. Public agencies, such as departments of agriculture, forestry, and public health, are all under pressure to explain and justify their uses of pesticides to a public increasingly concerned about pollution. While our primary role in pesticide registration is in the protection of fish and fish habitat, we have some sympathy for other pesticide user groups since fisheries management agencies have frequently found themselves using pesticides, for example, to control undesirable fish species, to control parasites like the sea lamprey, or to control fungal diseases in hatcheries and aquaculture facilities.

The problems of chemical pollution have been recognized at many different levels, as judged by the creation by government departments of environment in many countries. A perceptive statement of the problem was given by Pope John Paul II, reprinted in *Science* (1980): "Man today seems always menaced by what he produces. This seems to constitute the principal act of the drama of human existence today." But for the most part people do not produce chemicals without reason, and certainly not in the case of pesticides. Canadian

*This section was written by W.L. Lockhart. The views expressed in this report represent those of the author and should not be considered the policies of the Canadian Department of Fisheries and Oceans.

farmers are businessmen in a competitive world market, and they do not buy pesticides because they want to spend their money that way; they buy them because they need effective pest control to stay in business. We know that Canadian farmers spent about $740 million (1984/85 figures) on pesticides (74% herbicides) and that they apply about 34 million kg of pesticides annually. In the past it seems that we have used the chemicals for the benefits they promised, and later we have found the menace in biological effects we had not anticipated. Now our registration procedures are aimed trying to evaluate both the risks and the benefits prior to reaching a registration decision.

If we look at world population growth, now some 5 billion (Fig. 16.3), then it is hard to see how the chemical pollution problem will get any better. In terms of our own numbers we continue to create a different kind of world from that of our history. As increasing numbers of people seek improved standards of living, there seems likely to be growth in the demand for more and better pest control, with the accompanying demand on the environment to assimilate greater chemical loadings. Some people will believe almost any scenario about the meaning of those chemicals for the environment and for themselves. In Lewis Carroll's *Through the Looking Glass* the Red Queen said, "Why sometimes I've believed as many as six impossible things before breakfast," and that sentiment sometimes applies to perceptions about environmental chemicals. I have attended public hearings on pesticide uses in Winnipeg, and I have listened to people express their beliefs about the dangers of chemicals in the

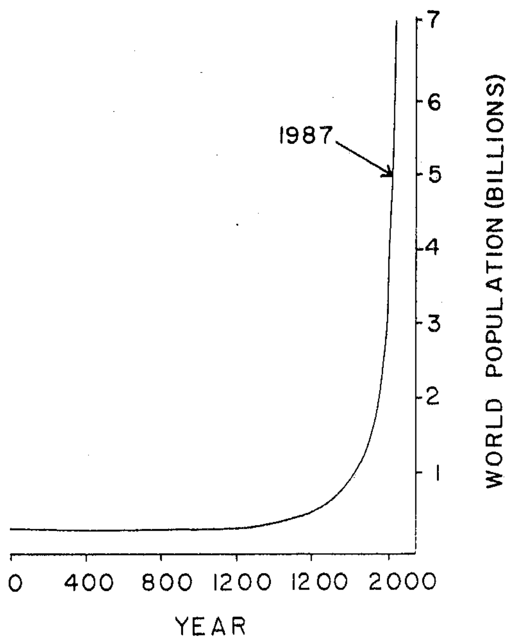

Figure 16.3.

environment. Sometimes the beliefs really are impossible, and sometimes they are sound qualitatively, but amplified out of realistic proportion. I recall one citizen's announcement that 2,4-D was causing cancer in farmers who use that herbicide, and I can remember being unable to find any convincing evidence in support of that. Now I understand that 2,4-D is indeed being investigated for that very effect.

People often complain that they cannot get what they regard as unbiased information about pesticides. It seems that the glossy brochures and instruction booklets are always those from the pesticide manufacturers. One published study of where pesticide users get their information was that of Turpin and Maxwell (1976) who analyzed the way Indiana corn farmers made decisions on their use of soil insecticides. They found that farmers used information from pesticide dealers to define their soil insect problems (45.8% of farmers), to decide what the solution to their problem was (63.2% of farmers), and to select the best insecticide (71.4% of farmers). This seems a clear conflict of interest.

The Fisheries Act contains provisions designed to limit the introduction of harmful chemicals into water, and we have a Fish Habitat Policy (Department of Fisheries and Oceans, 1986) intended to conserve the quality of habitat important for fish. There have been enough convincing cases where pesticide applications have had undesirable side effects on fish and wildlife to cause agencies responsible for the conservation of those species to become cautious about pesticides. The institutional arrangements regulating the use of pesticides have been developed following the scientific understanding of the effects of earlier uses of pesticides before regulations were in place. We recognize how little we can do about pesticide pollution after it has occurred, and we now try to focus our attention on prevention of undesirable side effects. The Department of Fisheries and Oceans has the opportunity to review data submitted by the industry in support of applications to register and market pesticide products. Based on those data a judgment is made on the acceptability of the registration in terms of risk to fish and fish habitat, and that judgment is forwarded as advice to Agriculture Canada where the final decision is made.

Generally, our reviews are based on the data supplied by chemical companies to Agriculture Canada and on data published in the open literature, but sometimes the department also conducts independent field or laboratory research. In these instances private companies and other government agencies have been helpful in providing information and samples for testing, especially samples labeled with radioactive tracers. Agriculture Canada's program of supplying analytical standards of pesticides has been particularly welcome.

5.1. Sample Cases

Most clear examples in which pesticides have become pollution problems occurred before the establishment of the current system of pre-use reviews. Early cases also preceeded the development of gas–liquid chromatography and particularly the electron-capture detector, and this technology has been a key factor in tracing the environmental dynamics of organochlorine pesticides. The presence of residues has in turn been a key factor in supporting cause–effect arguments.

One of the most widely cited cases has been described for Clear Lake, California (Hunt and Bischoff, 1959), which was treated with DDD, starting in 1949, to kill *Chaoborus* gnats. The gnats virtually disappeared for two years and then began to reappear and increase in abundance until the lake was treated again in 1954. Late in 1954 and early in 1955 biologists began to find dead western grebes in the lake and no infectious diseases could be identified. Gnat populations increased again and a third treatment of the lake was carried out in 1957, and again dead grebes were found. On this occasion the fat of some of the birds was analyzed and found to contain high concentrations of DDD. This prompted the collection of fish and they too were found to have high concentrations of DDD. The nesting population of western grebes had historically been over 1000 pairs, but by 1959 it was only 15 pairs and even these were thought to have raised no young. In this instance the pesticide made its way from the water to the fish and then to the fish-eating birds, where the effect was noticed.

Perhaps the clearest cases of effects of pesticides on Canadian fish populations were described in the 1950s and 1960s during widespread use of DDT to control forest pests. Extensive kills of Atlantic salmon, brook trout, suckers, minnows, and invertebrates were reported in New Brunswick streams and rivers, with further delayed mortality noted at the onset of winter (Kerswill, 1967). Comparable kills of young salmon and trout were found in streams on northern Vancouver Island during forest spraying there in 1957 (Crouter and Vernon, 1959). These experiences provided some of the most compelling arguments in favor of replacing DDT with alternative compounds. Since then we have learned that DDT has permeated the planet. In 1969 it was identified in snow samples from the Antarctic (Peterle, 1969) and we know it is now ubiquitous in the biosphere.

More recently toxaphene has been turning up almost everywhere. It has been found in fish from the Gulf of St. Lawrence (Musial and Uthe, 1983) and fish from the Great Lakes (Rice and Evans, 1984). It is the major organochlorine compound in samples of fish from the Mackenzie River drainage (unpublished data). For example, the liver from a burbot (*Lota lota*) from Arctic Red River contained over 5 μg/g (wet weight) of toxaphene. The liver of this species is rich in fat and has historically been consumed by Dene people as a delicacy. At a level of 5 μg/g a single burbot liver would supply several times the "acceptable daily intake" of toxaphene (1.25 to 2.5 μg per kg body weight per day) (*United States National Academy of Sciences, 1977*). The situation is even worse with lake trout from the upper Great Lakes where toxaphene levels around 7 μg/g have been reported by Rice and Evans (1984). Like other organochlorine compounds (DDT, PCB, etc.) toxaphene components move with air currents (Rapaport and Eisenreich, 1986) and contaminate sites remote from any use of the pesticide. Toxaphene has recently been banned from further uses in North America, but that does little to deal with the residues already in place. Chlordane, another organochlorine pesticide, follows toxaphene, and PCBs in fish from the Mackenzie drainage, and it also has been identified in air samples from the Northwest Territories (Hoff and Chan, 1986). How did chlordane find its way into the air in Arctic Canada (Mould Bay)? Did it come from North America or did it come over the Arctic Ocean from Europe or Asia? If there are multiple sources then each can implicate the other. "My brother did it" is always a good defense.

Many of the more recent pesticides are unstable in the environment, and we do not have residues to help trace exposure. We may have fragments of the parent chemical but we may not be able to establish that they came from the pesticide. In these cases it is more difficult to associate any biological responses with exposures to the pesticide. However, given that pesticides do reach beyond the target pests, what does that mean to those unfortunate creatures, the "nontarget organisms"? The toxicological literature on lethal and sublethal effects of pesticides on experimental animals is enormous. We can find these effects at all the different levels of biological organization. At the subcellular level an entire journal (*Pesticide Biochemistry and Physiology*) is devoted to studies describing the biochemical and physiological effects of pesticides. At the anatomical level, structural deformities in fish as a result of experimental exposure to pesticides have been reported (e.g., vertebral damage) (McCann and Jasper, 1972). Attempts have been made to work backward from vertebral damage in a population of fish to explain the deformities as a consequence of earlier pesticide exposure (Baumann and Hamilton, 1984). Subtle behavioral changes have been described in fish exposed to pesticides (Bull and McInerney, 1974) and dramatic changes in the drifting behavior of invertebrates have been described repeatedly following treatments of Canadian rivers with pesticides (Flannagan et al., 1979). The widespread emergence of pest species resistant to pesticides that have been used to control them is a good example of pesticides altering gene frequencies in populations (World Health Organization, 1970). Even at the psychological level an important human reaction to chemical pollution is the fear people express. An editorial in *Science* (Marshall, 1982) described a U.S. court ruling that required the Nuclear Regulatory Commission to deal with the fears of people near the Three Mile Island nuclear plant, whether or not those fears had a rational basis. Citizens' fears of exposure to pesticides have been expressed at several public hearings associated with pesticide use in Manitoba.

Sometimes we may be able to see a clear effect of a pesticide at one level of organization but not understand what that implies for another level. As an example of this, experience is cited with fish in ponds in Winnipeg during a Public Health emergency in which the whole city was sprayed with malathion (Lockhart et al., 1985). Immediately after spraying, the brain cholinesterase activities in walleye fell to only 26% of prespray values and then recovered to near prespray values over about two weeks. A second spray was applied about three weeks after the first, and the cholinesterase response was very similar. However, apparently no fish were killed, and the only ecological response noted was a short-term cessation in growth. Thus, the biochemical observations were clear but their ecological implications were not. This state of knowing something at one level of biological organization but of not knowing how to translate it to another level of organization is not uncommon.

The case of bioaccumulation of DDD in birds in Clear Lake cited above (Hunt and Bischoff, 1959) is an instance of food-chain biomagnification of pesticide residues. The consumption of organochlorine-contaminated fish by mammals can be harmful to mammals, especially to processes of reproduction. For example, mink fed on coho salmon from Lake Erie averaged over four pups per litter, while those fed on coho from Lake Michigan averaged less than one (Aulerich et al., 1973). The salmon from Lake Erie were found to contain much lower levels of DDT and dieldrin than those from Lake Michigan, and these materials may have been the cause of the reproductive impairment in the mink. Marine mammals feeding on fish are particularly vulnerable to accumulation of contaminants from the fish, and organochlorine compounds including DDT have been suggested as the cause for reproductive failure in Baltic seals (Helle et al., 1976) and of premature births in California sea lions (DeLong et al., 1973), although the experiments would not isolate the effect of DDT from that of other chemicals like PCBs. More recently, experimental feeding has shown that a diet of fish taken from the Dutch Wadden Sea, an area receiving the discharge from the Rhine river, can cause reproductive failure in seals (Reijnders, 1986). Low birth weights have been reported in babies born to people residing the Love Canal area of New York (Vianna and Polan, 1984).

In view of the ability of pesticides and other chemicals in fish to cause harmful effects in mammals consuming the fish, it is not surprising that agencies charged with protecting public health set limits on the contaminant levels allowed. However, Canadians (like other people) have become contaminated with a range of stable pesticides (chlorobenzenes, lindane, oxychlordane, *t*-nonachlor, heptachlor epoxide, dieldrin, and DDT) in spite of the efforts to limit exposure (Mes et al., 1982). Fish can accumulate contaminants to some level below a toxic threshold for the fish themselves but still represent a threat to consumers, just as the fish in Clear Lake, California, in the 1950s were hazardous to the western grebes feeding on them. This type of contamination can destroy fisheries by closing markets. Contamination can also require expensive inspection programs to analyze the fish and ensure that only those below the safety limits ever reach markets. Even the perception of a threat of contamination can influence markets, whether the threat is real or not.

5.2. Regulatory Role

The responsibility of the Department of Fisheries and Oceans can be stated very simply. We want to maintain Canada's ability to produce fish, to enhance that ability where we can, and to make sure that the fishery products are wholesome. In making a judgment about the use of a pesticide, a range of socioeconomic arguments come into play. These arguments are difficult to reduce to the required "yes or no" decision on the use of a pesticide, particularly when the costs and the benefits apply to different sectors of society or accrue over different time scales. With a pesticide the cost may occur as some contamination or biological stress on fish or wildlife or other "environmental" components generally and it may occur over decades, while the benefit may be in crop yield or forest growth or public health right now. Our input to the registration decision is generally on the cost or risk side of the balance that must be weighed by Agriculture Canada. We can produce dollar figures, like the value of sales of commercial fish, the value of the sport fishery that might be placed at risk, or the cost of inspection programs, but the party on the benefit side can do the same and those figures may be even larger. It is often easier to associate dollars with the proven and measurable benefits than with uncertainties of possible costs, particularly over short time periods. Consequently it is easy for the "environmental" values to lose short-term socioeconomic arguments.

When our examination of the data supporting a registration is complete, it is given as advice to Agriculture Canada where the final registration decision is made.

5.3. Need for Better Conceptual Models

It seems reasonable to assume that the primary toxic interaction between a pesticide and an organism is at the molecular level. A wide range of sublethal cellular and metabolic effects have been shown to follow from experimental exposures of fish to pesticides, but then it becomes a problem of understanding what the sublethal events mean at higher levels of biological organization. For example, a cell biologist or biochemist might have a good understanding of events within a cell, but have difficulty establishing what the subcellular events mean to the whole organisms. As life scientists we have failed to develop good conceptual models to lead us from the primary interaction between the organism and the chemical at a molecular level through to the responses meaningful to us at population and community levels. When dealing with fish and wildlife, we need to make the jump to ecological levels because individual organisms may have little impact on the population. This is not to say that the injury or death of individuals is meaningless. Experiences with human or veterinary medicine can help us, but these disciplines can often afford to stop at diagnosis and treatment of the individual patient. When dealing with fish and wildlife we have to find ways to proceed to still higher ecological levels of organization.

Concepts of ecosystem stress are beginning to emerge (Rapport et al., 1985), based on Selye's earlier studies, and these may provide the framework needed. However, a valid conclusion that an ecosystem is in a state of stress may offer little help in identifying the components that have given rise to that state. The paradox is that measures with the greatest diagnostic potential have uncertain ecological meaning, and measures with the greatest ecological meaning have uncertain diagnostic capability.

5.4. Ethical Responsibility

Fundamentally the argument is not an economic one based on which set of dollar figures is more persuasive, nor is it a purely scientific one based on an understanding of ecological effects. Rather, the argument is an ethical or religious one. We must protect the environment *because it is right to do so*. No more fundamental argument can be made, and the question is whether Canadian citizens as a voting body accept it. Public opinion polls have suggested that Canadians do care deeply about the environment and will make economic sacrifices to protect it. The widespread distribution of pesticides throughout the biosphere is a good example of "tinkering" on a planetary scale. A comment by Aldo Leopold (Leopold, 1949) bears repeating: "To keep every cog and wheel is the first precaution of intelligent tinkering."

6. ASSESSING AND REGULATING THE ENVIRONMENTAL EFFECTS OF PESTICIDE USE*

There is little doubt that today's commercial agriculture is dependent on the use of pesticides. Modern forestry practice is also wholeheartedly embracing the principles of pest control. The depth of the dependence on pesticides that is necessary for production of food and fiber has been and will continue to be an arguable point. If trends hold, we will continue to increase our standards of living by continually increasing yields per unit area of both food and fiber. This will create a sustained demand for some form of pest control and, for the most part, this control will continue to be provided by chemicals.

This section examines critically how the environmental effects of pesticides are assessed and managed. This is done not with the intent of accusing or laying blame, but rather with the intent of demonstrating where there are opportunities for strengthening our abilities to assess and manage pesticide impacts. This will be my perspective not necessarily that of Environment Canada.

At present there is an elaborate system in place for measuring and controlling pesticide impacts. There is evidence that it is largely successful, in that we are not faced with pesticide-induced, ecological problems of catastrophic proportions (see Section 4.1, however). There are several disturbing trends, however, that indicate the need to increase our efforts in the area of pesticide control.

The first of these trends is that with the introduction of each new type of pesticide compound there has been a decrease in the rate at which that compound is applied. We began in the early 1940s by applying DDT at a rate of

*Section 6 was written by W.R. Ernst.

about 1.5 kg/ha. This was followed by the introduction of organophosphates (such as diazinon and malathion) in the late 1940s and early 1950s, which were applied at rates of 0.5 to 1.0 kg/ha. The carbamates (such as carbaryl and aminocarb), first introduced in the late 1950s and 1960s, further reduced the dosage to 0.25 to 0.5 kg/ha. We are now using synthetic pyrethroid pesticides which are applied at only 0.02 kg or less per hectare (Knüsli, 1985). This means that we are using ever increasingly toxic compounds to do the same job. While the specificity of some of these chemicals has been increased so that they may not be as toxic to birds and mammals, they are still as broadly toxic to 95% of the species in the animal kingdom, namely the invertebrates (Hickman, 1973). This use of ever increasingly toxic compounds means that the margin for error in being able to protect nontarget invertebrate species is being reduced.

Another disturbing trend is that the number of target insect species that are resistant to one or more insecticides is increasing at an exponential rate. In 1955, there were only approximately 25 insect species known to be resistant to control chemicals. As of 1980, there were about 450 insect species displaying some degree of resistance to one or more insecticides (Bottrell and Smith, 1982). From an operational point of view this means that to obtain the same degree of control, either increased application rates of the same type of insecticide must be used, or new insecticides must be developed. This fact, combined with the previously mentioned need to increase yields on a per unit area basis means that we are locked into what has been aptly called the "pesticide treadmill"(Van den Bosch, 1979). In other words, once you are on the treadmill, you no longer retain the option of getting off and you must continually move faster just to stay in the same spot.

The fact that total pesticide sales in Canada skyrocketted from about 55 million dollars in 1970 to about 190 million dollars in 1977 (Agricultural Institute of Canada, 1981) is a forceful indication of just how fast this treadmill is moving. Unfortunately, the collection of data on comprehensive national pesticide use in Canada ceased in 1977, so we have no idea of how much is sold now.

This information is not presented with the intent of suggesting that we try to get off the pesticide treadmill, because we do not have the technology to do so. The principles of integrated pest management (IPM) have been reasonably well established for over 25 years (Stern *et al.*, 1959) and yet they still offer only marginal hope of reducing our dependence on pesticides. Likewise, the development of more pest-resistant varieties of crops through biotechnological advances offers some hope for reducing pesticide needs (Worthy, 1984), but, this will probably come slowly.

The purpose in discussing the depth of our dependence on pesticide chemicals is to demonstrate the magnitude of the problem in assessing and regulating their environmental impacts and to indicate that these problems will probably get worse before they get better. The public is also beginning to develop an appreciation of the problems that are involved in assessing and regulating pesticides. I would agree with those who believe that we now live in a chemophobic society (Bolker, 1986) and that there has been considerable overreaction to the pesticides issue. Nonetheless, the vocal public is exerting considerable pressure on politicians and regulators to ensure that all toxic chemicals, but particularly pesticides, are properly regulated. Unfortunately, in the eyes of many members of the public and, to be fair, in the eyes of many of the government regulators themselves, we are doing a less than creditable job of managing these toxic chemicals (Hall, 1986). This view has been supported during the recent review of the federal Department of Environment by the Nielson Task Force (Anonymous, 1986), which indicated that the Environment Canada record in toxic chemicals management is poor and is primarily a consequence of weak and fragmented environmental protection legislation in Canada.

6.1. Pesticide Registration

The principal mechanism for controlling pesticide use in Canada is registration of all pesticides in commerce under the authority of the Pest Control Products Act. This act is administered by Agriculture Canada, but, during the preregistration review of a particular product, Agriculture Canada solicits the opinion of technical experts from Health and Welfare Canada, the Department of Fisheries and Oceans, and Environment Canada. Therein lies one of the first problems we encounter with controlling the environmental effects of pesticides. While Health and Welfare Canada has a formal "Memorandum of Understanding" defining the nature of the relationship between these two departments, Environment Canada's relationship with Agriculture Canada has no formalized agreement. There has been an effort to establish a "Memorandum of Understanding" between the two departments for over four years; however, it has not come to pass. This means that Agriculture Canada calls upon Environment Canada to review information only as Agriculture Canada sees fit and is under no formal obligation to accept the advice that is offered. To be fair, the working relationship between the two departments is good, but there have been instances when Environment Canada's advice has been ignored.

The preregistration evaluation of pesticide products is probably more thorough than for any other chemicals in commerce. A measure of this thoroughness is the often quoted fact that to obtain the information necessary for a complete modern pesticide registration package may take 9 to 10 years and cost upward of 30 million dollars. There are several qualifiers that must be mentioned to put this fact in perspective. The first is that most of the data for agricultural pesticides are generated primarily for registration in the U.S. market. (The situation is different for forestry uses, where most of the data are generated under Canadian situations.) Much of the environmental fate and effects information is therefore generated under U.S. conditions with species that may not be endemic to Canadian environments. Where this is judged to be a problem, a request is usually made to prospective registrants to generate more locally relevant information that may be used to review purposes (Millson, 1986). A specific set of guidelines for the environmental fate and effects information needs to be established for registration. These guidelines should demand data relevant to the Canadian situation. Guidelines have recently been drafted for environmental chemistry and microbial and biological pesticides but they are not yet satisfactory to Environment Canada advisors. Guidelines have yet to be established for environmental toxicology requirements.

It is also important to recognize that the information reviewed prior to registration is generated by the prospective registrant (in many instances with their own personnel, but generally by contract investigators). The Industrial BioTest Laboratories experience taught us that information generated by these so-called "independent" contract investigators should not always be accepted as face value. Furthermore, because these testing facilities exist in other countries, Canada has no access to them and, therefore, is in no position to evaluate their capabilities for producing high-quality data. This would seem to argue for an audit or verification capability by those agencies responsible for evaluating submitted data. Health and Welfare Canada has decided, as has the Environmental Protection Agency in the United States, that departmental audit of certain pivotal information is necessary before registering a pesticide product. Unfortunately, Environment Canada has not begun to audit *any* of the information it reviews prior to registration of the product. It is now almost 10 years since the Industrial BioTest Laboratories affair and we still have not come to grips with the problem of verifying environmental information. This is a serious fault in the integrity of the registration process.

It is also worth noting that few of the presently registered pesticides have had anything that approaches an intensive review, since most were registered for use in the years when environmental impacts and human health effects were not adequately considered. It has been estimated that only 15% of the pesticide active ingredients presently registered have ever been reviewed by Environment Canada, let alone been subjected to the testing detail we now know is necessary to predict environmental fate and behavior (Millison, 1984). At present, there is an attempt on the part of Environment Canada, in cooperation with Agriculture Canada, to systematically evaluate this large number of currently registered pesticides which have had no environmental review. A high priority needs to be put on the systematic reevaluation of all currently registered pesticides.

6.2. Postregistration Evaluation

Once a pesticide has been evaluated it receives a registration, which dictates the way in which it may be used. Certain individuals, mostly the lay public, seem to have difficulty in accepting the scientifically logical fact that it will never be possible to prove the negative, namely that a pesticide will not produce adverse effects during operational use. Until the time of registration, however, the burden of proof has been to demonstrate that once the chemical is put into commerce, its use will not result in unacceptable environmental or health impacts. The chemical, until it is registered, is judged to be "guilty" until the weight of evidence demonstrates that it is innocent of being a potential environmental problem. After the pesticide is registered, however, that "burden of proof" shifts. The chemical is now judged to be *reasonably* safe and it must be demonstrated *positively* that the product causes harm before changes in its registration status will be considered.

This change in burden of proof is really the only logical approach that can be taken in registering pesticides. This creates a problem, however. Simply stated, it is after registration that the truly independent investigation into a chemical's environmental fate and behavior begins. This is the time that government agencies and academic researchers begin fate and effects studies. Because of this shifted burden of proof, the genuinely independent researchers must now demonstrate serious negative impacts before regulatory action will be taken.

Postregistration evaluation is also somewhat hampered by the fact that academic and many government researchers do not have access to the fate and effects information that is submitted to regulatory authorities. This is because such information is classed as confidential business information under Canadian patent laws. This means that the independent researchers must start from square one and repeat most of the fate and effects studies just to begin to focus in on potential problem areas—a process that takes years in some instances. Much valuable research time and effort could be saved if registration information was not classed as confidential. There are some efforts underway by the National Pest Management Advisory Board (Versteeg, 1986) to initiate changes in the rules regulating access to pesticide information. These efforts should be supported and nothing less than total access to all information should be tolerated.

The postregistration monitoring of pesticide impacts is one of the most important parts of the overall pesticide management process. Most of the preregistration evaluation is laboratory toxicity work (primarily acute lethality studies) and in some instances small-scale controlled field studies, which, with the exception of forestry pesticide, are usually conducted in another country (Rawn, 1986). It is only after the chemicals are in commerce that their effects under actual operational conditions can be measured. Field studies conducted under operational conditions do have the disadvantage of being much less controlled than laboratory or small-plot research trials. There are regimes of weather and application techniques to contend with, and no two receiving environments are the same. Well-conducted field studies, under operational conditions, have the advantage of measuring the end result of pesticide use after all the modifying factors have had a chance to operate.

Unfortunately, there are few investigators in Canada who are now monitoring field impacts of pesticides. Almost all of these are government scientists in environmental or resource agencies. It has been estimated (Environment Canada, 1984) that in 1984 within Environment Canada, which has a total staff of over 10,000 people, there were only 16 person-years dedicated to assessing pesticide use after registration. It is likely that only half of these people are involved in environmental fate and effects monitoring. This indicates an inadequate dedication of resources to the issue.

One of the principal problems in assessing pesticide impacts is determining what constitutes an adverse effect. It must come as no surprise to anyone that virtually all pesticide use causes nontarget mortality. The real trick is being able to determine when these impacts become ecological problems. Some ecologists (Hall, 1986) have argued that a severe impact is indicated by measurable changes in ecosystem structure or function, while others are of the opinion that this measurable change must continue for a period of time, such as one annual cycle. This is not the time to explore this concept. The point is that determining what constitutes a significant ecological impact is within the realm of scientific judgment. Unfortunately when it comes to pesticide impacts, researchers have been reluctant to make and put forward these judgments. Furthermore, if such judgments are to become part of the decision-making process they must be properly directed and defended vigorously.

6.3. Provincial Regulation

Provincial authorities are responsible for authorizing the use of pesticides within their jurisdictions. They may add stipulations to the use permit and, therefore, in principal, are able to act as a second-tier mechanism for pesticide review. Unfortunately, in most cases, they are hampered in this activity by two factors. The first is that they are not allowed access to the registration review information and must base their decisions on the limited data in the open literature. Second, they do not have the staff resources to review the environmental implications of each pesticide on a case-by-case basis. Accordingly, provincial pesticide use monitoring generally consists of an observance of compliance with permit restrictions and there is not much effort directed toward measuring environmental impacts.

6.4. Concluding Remarks

It is incorrect to leave the impression that pesticide assessment and management is in a state of disarray—it is not. Pesticide chemicals as a group are probably more intensively and extensively evaluated for potential problems both before and after they are introduced into commerce than other commercial chemicals. The rigor of these evaluations has restricted the registration of new active ingredients to an average of about five per year over the past eight years. Making it increasingly difficult to register pest control products can be double-edged sword that must be wielded carefully. There could come a point when, in an honest but zealous attempt to prevent the introduction of a chemical into commerce, one could prevent the displacement of a currently registered chemical with environmental effects that may be substantially greater. In other words, we should not become so rigorous in our evaluation demands that we economically impede the development of newer, possibly more environmentally benign, products.

Some steps that could be taken to greatly improve pesticide management abilities in Canada are as follows:

1. To ensure that environmental advice is given due respect, a "Memorandum of Understanding" should be required between Environment Canada and Agriculture Canada.
2. Preparation of guidelines for detailed environmental fate and toxicity data requirements should be expedited. These guidelines must be specific to the Canadian situation and be satisfactory to Environment Canada advisors.
3. The authenticity of submitted environmental registration data should be verified by selectively repeating certain pivotal tests in independent laboratories.
4. A high level of effort needs to be directed toward the systematic reevaluation of all presently registered pesticides according to existing evaluation standards.
5. There needs to be freer access to the data submitted in support of registration.
6. There needs to be an increased level of effort dedicated to evaluating environmental impacts of pesticides after they are registered.
7. Finally, scientists, particularly those from independent research facilities, must be more willing to make clear judgments on the ecological importance of measured impacts. Also, they must not hesitate to direct these judgments, by whatever means or channels they feel necessary, to the proper people.

Many people are indicating that, with new developments in biotechnology and biorational control agents, we are on the brink of a new era in pest control (Science Council of Canada, 1985). If that is the case, we will be hard pressed to keep up with these developments with the control strategies we now have. Environment Canada has just come to the realization that our legislative mandate for toxic chemicals is inadequate, and it is in the final stages of implementing new toxic chemicals legislation. Efforts to find alternative control strategies are to be encouraged, but this is proving to be a catch-up game and we need to move much faster if we are ever going to provide an assessment and regulatory process that is satisfactory to all the stakeholders involved.

7. GENERAL OVERVIEW*

The registration process for pesticides in Canada is strict, even stricter than that for pharmaceuticals. That is as it should be because pharmaceuticals present a risk only to the treated individuals, whereas pesticides present a risk to entire

*Section 7 was written by D.C. Eidt.

communities. Strict as the regulations may be, they are subject to the simple principle already cited, that, stated another way, says that if something is convincingly demonstrated it is proven, but something not demonstrated is not disproven. Thus, the constant vigilance and cooperation of all organizations concerned about the benefits and hazards of pesticides is needed. There is everything to be gained or maintained, because environmental protection is in everybody's best interest. Agriculture and forestry cannot risk the loss of pesticides as critical tools of production; industry cannot risk the loss of products in which it has invested millions of dollars.

A sixth element in the pesticide controversy is public opinion and in particular the environmentalists who purport to represent it. That is not to say that Environment Canada is insensitive to public opinion, but the response is indirect through government and departmental policymakers. Environmentalists have been keen watchdogs whose concerns have led to many changes in the way pesticides are regulated. Once ruled more by emotion than rationality, they have become increasingly sophisticated and, like scientists, businessmen, and resource managers in fisheries, agriculture, forestry, the chemical industry, and government, are becoming increasingly aware of the benefits and costs and conflicts of interests involved in pesticide usage.

In summary there is general agreement on the following grounds pertaining to pesticide use:

1. Pesticides will be with us into the indefinite future, and we will have to cope with them in aquatic habitats because of the ubiquitous nature of water.
2. We have a good pesticide regulatory process in Canada that is being constantly improved.
3. National regulation may not be good enough for us and our neighbors. We have to think and regulate hemispherically or even globally.
4. The regulatory process is not perfect, but it will continue to improve. A system based on antagonism is not the best way to improve it.
5. The environment is not negotiable. One cannot put a price on some things, and the trade-offs will be judgmental rather than cost-benefit exercises.

Much of the body of data in a registration package is not available for postregistration scrutiny. Therefore, persons concerned about possible environmental (or health) effects must start many of their investigations from the beginning, and are compelled to repeat work already done. Thus there are philosophical differences in approach to the study of environmental side effects: before registration, emphasis is on environmental safety; after registration, emphasis is on environmental hazard. Furthermore, evidence of the invalidity of a registration is taken seriously before registration and may delay or prevent it (guilty until proven innocent), but after registration, similar evidence will be vigorously opposed, has little chance of resulting in suspension of the registration, and may require a protracted conflict before deregulation or suspension occurs (innocent until proven guilty).

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