An Evaluation of Avian Impact Assessment Techniques Following Broadscale Forest Insecticide Sprays

Presented at the "Wildlife Toxicology Workshop", January 1984, Corvallis, Oregon

Pierre Mineau and David B. Peakall

Canadian Wildlife Service
Wildlife Toxicology and Pathology Division
National Wildlife Research Centre
Ottawa K1A 0E7
Canada
1. Introduction

Between 1952 and 1979, some 61 million hectares (or 151 million acres) of eastern North America have been sprayed for the control of the Eastern Spruce Budworm (Choristoneura fumiferana) alone (see Peakall and Bart, 1983). In eastern Canada, this particular control operation has resulted in approximately seven million kg of organochlorines, twelve million kg of organophosphates and one million kg of carbamates being broadcast over Balsam fir-spruce forests. The area sprayed over the last three decades has considerably increased. For example, 75% of the total area treated for the Eastern Spruce Budworm was sprayed in the 1970s. Given this recent intensification in budworm suppression programs, it is perhaps appropriate to ask about prospects for the future.

The Eastern Spruce Budworm is an endemic species that has co-existed with the fir-spruce forest presumably since the last ice age. Outbreaks are characterized by periodic high populations (typically for 6-10 years) with massive losses of trees followed by a long period of very low population density. The history of the outbreaks indicates that they have occurred more frequently in the 20th century than previously (Blais, 1983). Blais considers that the increases in extent, frequency and severity of outbreaks are largely attributable to changes caused by man, like, for example, clear-cutting, fire protection and pesticides. The persistence of the infestation in New Brunswick, where treatment
has been applied for 30 years, provides strong evidence that insecticides prolong outbreaks (Blais, 1973). The history of outbreaks in Québec indicates that the spraying may reduce the intervals between outbreaks (Blais, 1974). Recent information (Smirnoff, 1983) suggests that populations of budworm which have survived treatment with organophosphates and carbamates have greater energy reserves and vigour than control populations.

On a broader ecological scale, the use of insecticides to control forest pests cannot be separated from sylviculture as a whole. The difficulties of maintaining monocultures in the face of insect pests are now a common knowledge. An extreme example is the cotton industry of northern Mexico. Starting in the late 1940s, synthetic pesticides were used to control the boll weevil (Anthonomus grandis), and crop losses were greatly reduced. In the late 1950s, the boll weevil developed resistance to DDT, forcing a switch to the organophosphates. That set the stage for the rise of the cotton bollworm to severe pest status due to severe impact on its natural enemies and the relative ineffectiveness of organophosphates against the target insect. By the late 1960s, some producers were spraying 15-18 times per season and by 1970 the cotton industry was virtually destroyed (Luck et al., 1977). There is a growing tendency to manage forests much like any agricultural crop but, in theory at least, our forest managers are committed to the principle of Integrated Pest Management in order to reduce the dependence on chemical pesticides.
In 1976, a task force was assembled to evaluate budworm control alternatives for the New Brunswick government (CCED, 1976). The report concluded that "neither of the current levels of productivity (industry or forest) could have been attained without crop protection. Cessation of crop protection now would result in large economic losses in the forest-based industry over the next 50 years". The report considered that, ideally, an official policy on the forests should (1) maintain current industrial levels, (2) maintain a healthy and productive forest, and (3) refrain from dependance on a long-term spray program. However, the same report concluded that there was no viable alternative to chemical insecticides to achieve (1) and (2) above.

It seems that whether a broadscale spray policy is ecologically sound or not, the forest industry has locked itself into a cycle of annual control at least with respect to the Eastern Spruce Budworm. Since the use of chemical insecticides is likely to be an important part of this spray policy for the foreseeable future, we wish to ask two basic questions:

1) How well are the impacts of such spray programs on the avian fauna being assessed - is the methodology adequate?

2) How effectively was the information obtained from impact studies used to modify the spray programs in order to minimize subsequent impacts - is there a viable feedback mechanism?
In the context of forest insecticide sprays and their impacts on wildlife, birds have been more studied than any other terrestrial vertebrates. This is partly for political reasons since, in North America, federal authorities have a strong mandate for the protection of migratory birds, and partly for biological reasons because the choice of birds as indicators also relates to biological realities.

Small forest mammals are secretive and hard to study and forest sprays are much less likely to penetrate to their habitat than to the habitat of canopy living songbirds. According to Buckner and McLeod (1975) field studies have not been able to show any gross impacts of forest sprays (whether DDT or common OP and carbamate insecticides such as fenitrothion, aminocarb, phosphamidon and mexacarbate) on small mammal populations. The safety margin might not necessarily be very large. For example, in the case of fenitrothion, breeding interruptions were recorded in a number of small mammals under simulated spray regimes at current application rates for budworm (Buckner et al., 1977).

Amphibians have been comparatively little studied, partly because of their secretive nature, also because they are relatively poorly represented at higher latitudes where the bulk of forest spraying has taken place and because they rank very low in the eyes of most wildlife managers. Field studies have demonstrated significant impacts on amphibians with DDT but not with phosphamidon, fenitrothion, aminocarb or mexacarbate (reviewed by Pearce
and Price, 1975). Peak concentrations of fenitrothion expected in stagnant ponds following aerial spraying at current budworm dosages (Lockhart et al., 1977) are two to three order of magnitude below the static LC50 calculated for tadpoles of the Northern Leopard Frog (Rana clamitans) (Lyons et al., 1976). There is no room for complacency however, since many of the sub-lethal effects documented in the laboratory have not been examined in the field. For example, Mohanty-Hejmadi and Dutta (1981) have documented that levels of fenitrothion as low as 20 ppb (the lowest concentration tested and well within the limits of pesticide levels recorded after field applications) can interfere with the embryonic development of the Indian Bull Frog (Rana tigerina). No one, to our knowledge, has even systematically documented the populations at risk, eg., what species are likely to be impacted on the basis of their life habits and their developmental stage when the spraying takes place.

2. Assessing the Impact on Birds

Two approaches stand out as being the most practical for routine impact assessment following forest sprays: population census and measurement of cholinesterase depression. These assessments have been carried out both on small experimental plots (eg., 40 ha for initial impact assessments by the Canadian Forestry Service) and in larger operational spray blocks. The advantage of the small plot is that the investigator has more
control over the study. Further, it may be the only possible option when the avian impact study is conducted simultaneously with efficacy trials as is often the case for new experimental insecticides. A major limitation is that mortality and cholinesterase inhibition may be masked by replacement of birds from outside the spray area. For example, Stewart and Aldrich (1951) and Hensley and Cope (1951) showed that through intensive and prolonged collecting of singing males, over twice the number of birds were removed from the study plot than were originally thought to be present. Replacement of territorial males usually took place during the night or in the morning following their removal. This is undoubtedly an extreme situation since, under forest spray situations, many of the "floaters" or replacement birds will also have been exposed to the spray. A further limitation of a small spray block is that effects may be masked by birds leaving the spray area to feed. This possibility, however, needs to be documented. The huge blocks of forest sprayed in eastern Canada reduce these problems, but make control areas hard to find. The lack of control over the spray operation can be a problem since it is often difficult to know well ahead of time the area to be sprayed and the exact timing of spray operation.

Independent of the size of the spray block, problems arise from the fact that forest spraying often occurs before the migration of all species is completed and movement of late migrants may mask any effects. It is therefore advisable to restrict the assessments to a few indicator species. Species which migrate early,
such as the Ruby-crowned Kinglet (*Regulus calendula*) and White-throated Sparrow (*Zonotrichia albicollis*) are especially well suited for this purpose since the former inhabits the high canopy and the latter frequently nests in clearings where it is more exposed to spray.

2.1. Population Census

Two approaches have been widely used to determine whether or not population changes have occurred following spray operations. These are: 1) the intensive coverage of small plots and, 2) line transects of up to 5 km in length. Other methods (e.g., mark-recapture) have been used on occasion but they are generally considered to be too labour intensive for routine monitoring.

The studies of the Canadian Forestry Service are carried out by assessing the forest songbird population on 4 ha plots using the singing male technique described by Kendeigh (1944) and Buckner and Turnock (1965). Populations are monitored daily and recorded on plot maps starting about five days prior to the application of the insecticide and continuing until five days after treatment. This approach enables territories to be plotted and thus the fate of individuals is followed. The major disadvantage with the small plot approach is that, in a typical aerial spray operation, insecticide coverage of the target area is far from uniform and a plot may be under- or over-sprayed or perhaps not sprayed at all. Many plots are therefore needed to assess the
impact of insecticide sprays. Furthermore, as Emlen's (1971) calculations indicate, the efficiency in terms of area covered per unit time is low and the numbers generated are frequently too small for statistical analysis. The standard plot size used in most Canadian studies has been 4 ha, whereas the recommendation of the International Bird Census Committee is 10 to 30 ha for closed habitats and 40 to 100 ha in open habitats (Svensson, 1970).

The studies of the Canadian Wildlife Service on the effects of forest spraying have been based on line transects of singing males (Fowle, 1965; Pearce et al., 1976). Repeated counts of singing male birds are made along roads and trails through the forest before and after spray treatment. Transects are approximately 5 km long and counts take up to three hours during early morning. This method gives less detailed information and may underestimate any decrease in vocal activity because songs become more easily heard as their total number decreases. The line transect method has the advantage over small plots in handling the problems caused by over- and underswathing of insecticide since, over a long transect, these effects tend to average out. As far as possible, transects are run at right angles to the line of spray emission. The results are best treated as simple indices without any attempt to convert them to absolute densities.

No single method of censusing songbirds will ever receive unanimous approval under all conditions. Much ink has flowed and will continue to flow on the relative merits of various census
techniques (see Ralph and Scott, 1981, for a prime collection of works on this subject). The fact remains that conditions prevalent in the boreal forest at budworm spray times must be some of the most difficult to contend with in the northern hemisphere.

In a recent study, Lehoux et al. (1982) compared the ability of these and other census methods to detect an impact following gross oversprays of phosphamidon (.44 and 1.12 kg/ha) and fenitrothion (1.40 kg/ha). Both the line and plot surveys fared poorly. Bad weather conditions played havoc with the data and in the case of one species, the White-throated Sparrow, no impact could be documented at the higher phosphamidon spray level even though 10 carcasses were recovered. The spray blocks measured 400 ha which, although large by small plot standards apparently allowed for rapid replacement of individuals. This replacement was documented through banding studies.

The number of recorded declines for individual species was greater with the line survey but the authors concluded that the plot survey was marginally more useful because effects seemed more consistent (even though fewer were significant on account of small sample sizes) and because a certain amount of qualitative data (e.g., territorial shifts or replacements) could be obtained. It is noteworthy that the authors were pooling data from four replicate 4 ha plots for both treatments and controls. Their overall conclusions were that plot surveys could be used if at least 15
to 20 hectares were surveyed in the center of spray blocks of at
least 2,000-4,000 ha in size. In this study, carcass counts and
banding efforts were deemed to be more useful than either plot or
line surveys.

In a recent paper, Peakall and Bart (1983), after reviewing a
large volume of survey data, favored the use of line transects and
uncorrected indices of singing males. The reason invoked for the
better overall performance of line transects was the high variabi-
licity on spray deposit which affects plot surveys more than it does
line surveys.

Either method when properly used is undoubtedly capable of
detecting catastrophic impacts such as those recorded with phospha-
midon and early dosages of fenitrothion. However, to unequivocally
prove a cause and effect relationship, it has still been necessary
to correlate population declines with the presence of sick and dead
birds. Scattered reports of impacts at the population level when
unaccompanied by body counts have not had much (if any) effect on
the way forest spray operations are carried out (e.g., Moulding,
1976). On the other hand, apparent declines of bird populations
following spray do not necessarily indicate lethality since song
depression has been observed in birds sub-lethally dosed with a
cholinesterase inhibitor (Grue and Shipley, 1981).
2.2. Cholinesterase Inhibition

2.2.1. The problem

We do not propose to review the justifications for using brain cholinesterase inhibition as a diagnostic indicator of organophosphate or carbamate intoxication; this has been done elsewhere (Ludke et al., 1975; Hill and Fleming, 1982; and others). We wish to consider the use of this assay in the context of forest spray only. Unfortunately, relatively little effort has been devoted to obtaining data on cholinesterase inhibition levels in birds following actual forestry sprays. We have been able to obtain the following studies (Table 1) and would be grateful for any other data.

Table 1. Information on cholinesterase levels following forest sprays

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Reference</th>
<th>No. species sampled</th>
<th>No. individuals collected in spray plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fenitrothion</td>
<td>Peterson, 1969</td>
<td>10</td>
<td>13*</td>
</tr>
<tr>
<td></td>
<td>Peterson, 1976</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Busby et al., 1981</td>
<td>5</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>Hamilton et al., 1981</td>
<td>3</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>Busby et al., 1983a</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Acephate</td>
<td>Julin and Gramlich, 1978</td>
<td>4</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Zinkl et al., 1979</td>
<td>11</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Zinkl et al., 1980</td>
<td>13</td>
<td>266</td>
</tr>
<tr>
<td>Aminocarb</td>
<td>Peterson, 1976</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Busby et al., 1982</td>
<td>5</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Busby et al., 1983b</td>
<td>5</td>
<td>203</td>
</tr>
</tbody>
</table>
Table 1 (cont’d)

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Study Reference</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichlorfon</td>
<td>Studholme, 1972</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Peterson, 1976</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Zinkl et al., 1977</td>
<td>10</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>Zinkl et al., 1977</td>
<td>12</td>
</tr>
<tr>
<td>Phosphamidon</td>
<td>Finley, 1965**</td>
<td>1</td>
</tr>
</tbody>
</table>

* includes four carcasses recovered post-spray
** data on whole blood cholinesterase only

In all of these cases, individual birds were collected with guns or mist nets at intervals after spray. We would like to point out some of the problems and pitfalls inherent in this sort of data and suggest ways in which they might be improved.

The first observation is that there is very little consistency in the way in which cholinesterase data are reported. Fortunately, after the suggestion of Ludke et al. (1975), several authors started reporting individuals with cholinesterase depression in excess of 20%, a level which, if good numbers of control birds are collected, usually falls a bit wide of two standard deviations from the mean value for unexposed individuals. Beyond this, there has been very little effort at standardization and we will later suggest some improvements.

Regardless of how the data are reported, they provide the experimenter with a formidable statistical challenge. One problem is that maximum cholinesterase depression is achieved at varying times after exposure depending primarily on the insecticide used.
and presumably the species involved. Sufficient numbers of birds cannot be collected at any one moment in time and collections usually take place over several days. It is therefore clear that, the sampling scheme and the way in which data are analyzed and reported have a great influence on the results obtained. For example, inclusion of a late sampling period after substantial enzymatic recovery would reduce an average inhibition level. Data from individuals collected immediately post-spray before inhibition is manifest would have the same effect. Yet, numbers are usually insufficient to provide adequate time trends.

Sampling is often carried out on relatively small spray blocks, and may be influenced by pre-spray temporary emigration of resident birds as well as post-spray immigration of floaters or replacements. This was discussed above in the context of population surveys. The greatest obstacle to meaningful post-spray collections of birds, however, is the dosage-dependant collectibility of individuals. Birds dosed with cholinesterase inhibitors typically exhibit ataxia, an unwillingness to fly and difficulty in perching; they appear apathetic to external stimuli and probably would not readily flush (reviewed by Grue and Shipley, 1981). Under laboratory conditions we have observed a strong tendency of birds to crouch in a corner of the cage following dosing. Since song production is also reduced, all these factors suggest that heavily dosed individuals are seeking sheltered locations and are less likely to be collected. This has already been suggested in the cholinesterase literature (Busby et al.,
1981). We believe that the reduced collectibility of heavily
dosed individuals is only minimally offset by some birds being
made more conspicuous as a result of poor co-ordination.

We suggest that data collected to date already show this
strong collection bias. Figures 1 to 3 summarize all the brain
cholinesterase data we were able to find for sprays of fenitro-
thion and acephate, the two insecticides for which the best data
exist. Even though we are making broad generalizations in pooling
species (at least, all are songbirds), formulations and delivery
systems, a positive relationship (Figure 1) between the proportion
of exposed individuals and the dose applied is still evident
(exposure is defined as inhibition greater than 20% or two stan-
dard deviations from the control mean; after Zinkl et al., 1979).
In Figures 2 and 3, actual % inhibition is indicated for those
birds which are shown to have been exposed. Interestingly, there
is no trend toward a greater level of inhibition at higher doses
and it looks as if the mean % inhibition level might reach an
asymptote before 50% inhibition is attained. Given the negative
correlation between the dose of cholinesterase inhibitors and
cholinesterase brain activity levels in lab studies (Ludke et al., 1975), and since we know from carcass searches and census
work that doses of 560 g/ha or higher of acephate and of 280 g/ha
or higher of fenitrothion are hazardous to birds (Peakall and
Bart, 1983), we conclude that the data in Figures 2 and 3 are
reflecting a severe truncation of the sample through removal of
the most affected individuals.
2.2.2. Possible solutions

One obvious solution is to recognize the limitations of the technique and to use the proportion of "exposed" individuals as a measure of impact. This seems to be a reasonable approach, especially in the context of a few standard indicator species. A second option would be to look for at least some individuals with high inhibition levels and adopt exact criteria of acceptability with respect to intensity and duration of the response. It might be proposed that it is not acceptable, for a forestry insecticide, to cause any individual to be inhibited by more than x percent for more than y days. Yet another option is to lower the range of acceptable inhibition to a level that is amenable to sampling, eg., 30-35% from Figures 2 and 3. It is possible that such a low "action level" may eventually be defensible on ecotoxicological grounds since preliminary efforts have been able to document an impact of sub-lethal inhibition on reproduction in Starlings (Sturnus vulgaris) (Grue et al., 1982) and White-throated Sparrows (Zonotrichia albiciollis) (Rusby and Pearce, 1983). In the latter study, a 40% depression level in one of the parents was associated with a measurably slower growth rate of nestlings. More of this type of information is urgently needed.

Whatever the approach, the reporting of cholinesterase data has to be standardized. We recommend that investigators adopt the system of Zinkl and co-workers (1979 and 1980) where individual
values are reported for all birds with a greater than 20% inhibition or, better yet, for all birds collected. Exact collection times should be given as well as all pertinent details of spray formulation and delivery systems. We suggest that species sex, age, weight and measurements (e.g., exposed culmen, wing, tarsus and tail) of all collected birds should be supplied so that a condition index can be determined. Total fat levels might also be useful in estimating the extent and importance of the anorexic (see Hill and Camardese, 1987) state brought about by exposure to the insecticide. Finally, spray impaction should be quantified with both glass plates (g ai/ha) and kromekote cards (number drops/cm²) in the upper canopy if possible and at least in clearings. Forestry sprays tend to be extremely variable (0 to 100% impaction) and a number of card/plate combinations will be needed as close as possible to the area of bird collection.

Whoever uses the data should recognize the bias inherent to it. Conventional wisdom has it that 50% inhibition of brain cholinesterase is indicative of a life-threatening situation. In practice, however, the usefulness of this or any higher level of inhibition as a warning or as a trigger for regulatory action is questionable if we cannot effectively sample individuals at that level of inhibition.

2.2.3. Caged bird trials

If caged birds reacted to a spray in the same fashion as wild birds, this would provide an answer to the problem of poor
collectibility of severely affected individuals. We know of two studies where this approach was tried. Unfortunately, these studies do not offer sufficient data to either recommend or abandon this approach.

Peterson (1969) placed caged English Sparrows (Passer domesticus) and Ring-necked Pheasants (Phasianus colchicus) in a forest clearing during an operational spray of fenitrothion at 420 g ai/ha. Wild birds were simultaneously collected. No details were given on the exact layout of the cage except that birds apparently did not have access to contaminated food. Three of 20 pheasants sacrificed at intervals of 4 to 48 hours post-spray had brain cholinesterase levels depressed by more than two standard deviations from the mean whereas most English Sparrows had cholinesterase levels significantly higher than the control birds. Because of this aberration, the experiment was deemed invalid. In any case, the maximum depression recorded in the caged birds was 58%. Half of the wild passerines recovered during the same spray operation had inhibition levels over 20%. One Swainson's Thrush (Catharus ustulatus) was found with 84% inhibition and four carcasses ranged from 75 to 82% inhibition.

Findlay et al. (1974) exposed Japanese Quail to a 280 g ai/ha fenitrothion spray in the Manitoba parklands. The pens were large and open at the bottom which meant that birds were in contact with and could consume contaminated foliage and insects. Spray cards indicated an even spray deposit throughout the area. Some cages were left in the open whereas others were placed under the White
Spruce canopy. Birds in the open were clearly more affected than those under the canopy as demonstrated by serum and brain cholinesterase levels as well as by overall pesticide body burdens. Although all birds maintained in pens in the open exhibited significant brain cholinesterase depression as determined by an analysis of variance, this depression only averaged 13% of control 8 hours after the spray. Individual values are not given but the lowest sample mean reported indicates a depression level of 32%. This compares poorly with other field studies (Figure 3) where, at the same application rate, significant numbers of collected songbirds had depression levels over 50%.

Although the approach taken by these two experimenters is laudable, the choice of two of the test species might be criticized. The galliformes are less at risk than small passerines because of their small surface to volume ratio. It is also likely that the input of contaminated food is smaller in a pen than in a wild situation and the dermal uptake is much higher in wild passerines as they move through contaminated foliage. Both dermal and inhalatory exposure might be increased in birds flying through a spray cloud. Fowle (1965) attempted to define how songbirds were exposed to phosphamidon by comparing the survival of birds sprayed directly with that of birds not sprayed directly but exposed to foliage contaminated by the same spray. Although the rates used were high and the experiments were not replicated, it did give an indication that contaminated foliage might be a more important route of uptake than direct spray impact. Work by the Canadian
Wildlife Service, in co-operation with the Canadian Forestry Service, is presently underway to evaluate more systematically exposure routes in songbirds by making use of spray simulators to minimize the variability in spray impaction. Further work on penned individuals subjected to operational sprays is obviously needed. It seems that the most fruitful approach will be to replicate the natural environment as closely as possible.

3. Conclusion

Earlier, we asked whether the methodology for impact assessment was adequate and whether there was sufficient information transfer between the ecologists and the foresters. As usual, there is no simple yes or no answer to either question. In the case of phosphamidon, impacts on songbirds were so severe, obvious and widely documented that the registration of that chemical for forest use was allowed to lapse. Where lesser impacts have been found and reported, as is the case for fenitrothion, we have not been as successful in influencing the forest industry. Even though our preference (based on comparative field studies) for an alternate pesticide (aminocarb) in the context of Spruce Budworm spraying has been widely known and officially stated (Pearce, 1980; EMOFICO, 1982; Pearce and Parker, 1983), fenitrothion continues to be the insecticide of choice in New Brunswick.

Before going any further, it is appropriate to ask what ornithologists are prepared to accept in terms of an impact on avian
populations and whether the foresters would agree. If every
single bird is to be protected in the spirit of the Migratory
Birds Act, then we have grounds to oppose a number of existing
spray programs. The principle of sustainable yield, however, is
well accepted for migratory birds which are harvested. Presum-
ably, a certain annual reduction in the number of forest songbirds
might not be detrimental to the population as a whole. Given the
number of species involved and the biological complexity of the
natural forest, the task of defining an acceptable impact is for-
midable. The possibility that some forest sprays have a sub-
lethal effect on the reproductive potential of certain species
means that body counts alone, even if accurate, could not give us
all the information we need. In the absence of better criteria,
we believe that our criticism of all the spray programs which
result in visible bird kills irregardless of their magnitude is
justified.

Keeping these considerations in mind, what type of study
would we recommend or require before potentially long-term forest
spray programs are undertaken? The two approaches discussed above
are the ones most amenable to a monitoring exercise. Unfortunat-
ely, both approaches have serious limitations. Once it is deter-
mined that a given insecticide will not create a hecatomb of birds
the census methods, as presently utilized by various monitoring
agencies, should be given very low priority. Collections of birds
for the assessment of cholinesterase inhibition are likely to be
more useful as the reproductive effects of sub-lethal depression
continue to be documented. Great care is, however, needed in the interpretation of these data. We believe that more emphasis should be placed on the few collected individuals that always show an inordinately high level of inhibition. Given the difficulty of collecting these individuals (see above), there is reason to believe that they truly are the "tip of the iceberg".

We do have to be careful about overreliance on any one method. The cholinesterase inhibition assay, for example, is useful in the context of organophosphate and carbamate pesticides and can even be made to differentiate between the two (Martin et al., 1981). The technique is of no use whatsoever with newer classes of insecticides, e.g., the synthetic pyrethroids.

In the end, conclusive evidence concerning the acceptability or non-acceptability of a forest spray operation is not likely to come from either small-scale censuses or collections of individuals for cholinesterase assessments alone. Labour-intensive assessments involving marked individuals and the documentation of a number of reproductive parameters are needed for an accurate assessment of impact at the population level. A key part of this approach would be the establishment of long-term study sites. Pearce (1980) has referred to the operational spray program's "amoebic quality", e.g., that in terms of area sprayed it has no constant form, moving one year in one direction, the next in another. Thus, long-term study sites would have to be sprayed as part of an agreement to conduct environmental studies. The areas would have to be large enough to overcome the problems of bird
immigration and emigration. Detailed studies of this type are obviously costly, but are probably the only way of ensuring that the persistent use of non-persistent insecticides are not causing long-term subtle effects on the forest ecosystem.

Any impact assessment program has to be economically feasible as well as scientifically sound. It is easy for armchair environmentalists to think of rafts of complex experiments that should be done on every chemical. While not wishing to contravene, the first amendment of the U.S. Constitution, which calls for the separation of church and state, we would like to suggest that the old English tithe of one-tenth, that was used to support the church, would be a reasonable amount to allocate to environmental research. In New Brunswick, it is estimated that $95 million (1976 dollars) were spent on crop protection between 1952 and 1976 (CCFD, 1976). For eastern Canada the total is probably $150 million, or $6 million/year. A monitoring program calling for the annual expenditure of $500,000 would not be unreasonable. This is an important point; before the start-up of any spray program that has potential environmental implications, the funding to research it adequately should be allocated.
Figure 1. The percentages of all individual songbirds collected following acephate, and fenitrothion spray operations that registered greater than 20% (or in some cases the greater of 20% or two standard deviations from the mean) inhibition in brain acetyl cholinesterase levels. Each point corresponds to a different spray event. Sources in the case of acephate include: Julin and Gramlich, 1977, and Zinkl et al., 1980, for 570 g ai/ha; Zinkl et al., 1979 (summer spray operations only), for 1130 and 2260 g ai/ha, and for fenitrothion: Busby et al., 1983 (raw data obtained from the authors), and Peterson, 1976, for 210 g ai/ha; Busby et al., 1981 (raw data), for 280 g ai/ha; Hamilton et al., 1981 (raw data estimated from graphs supplied), for 300 g ai/ha; Busby et al., 1983, and Peterson, 1969, for 420 g ai/ha.
Figure 2. Actual percent values for brain AChE inhibition following acephate sprays in those collected birds which were definitely exposed (eg., registered 20% inhibition). Each column of points represents a different spray event. The mean is shown as a horizontal bar and one standard deviation as a rectangle. Sources as in Figure 1 except for data from Julin and Gramlich, 1977, which were not available.
Figure 3. See Figure 2 for details. Brain AChE values following fentanyl sprays.
We are grateful to P.A. Pearce, D.G. Rusby, W.K. Marshall and M. Lis for critically reviewing earlier versions of this manuscript. We also wish to thank the U.S. Environmental Protection Agency for providing the forum for this discussion.


