MORTALITY OF LITTLE BROWN BATS FOLLOWING
MULTIPLE PESTICIDE APPLICATIONS

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Abstract: This study documents the mortality of little brown bats (Myotis lucifugus) at a nursery colony in southern New Hampshire in a 2 year period following multiple applications of pesticides (DDT, chlordane) for extermination. Mortality among adult females was greatest in the second summer (principally in the parturition period) following the last pesticide application. Two major peaks of mortality occurred in young bats, one soon after birth and another as they reached adult size. Significant age differences in mortality were observed between the first and second years after spraying. The percentage of young bats dying as they approached adult size was highest in the second year. Mortality was nearly 9 times higher in young than among adult bats in the first year, whereas proportionately more adults died in the second year. We suggest that the prolonged and latent mortality of bats following pesticide applications increases the short and long-term health risk to humans and therefore necessitates the reevaluation of current extermination practices.

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Most efforts to document accumulation of pesticide residues in insectivorous bats (Jeffries 1972, Reidinger 1972, 1976, Clark et al. 1975, Clark and Lamont 1976a,b, Clark and Prouty 1976, Geluso et al. 1976) arose out of concern for declining bat populations (Cockrum 1970, Stebbings 1970, Mohr 1972, Braaksma and van der Drift 1972, Findley 1973). These studies assumed that the principal route of pesticide entry was via the food chain, with bats as "non-target" species (Pimentel 1971). The application of DDT, chlordane, and similar compounds directly on bats or their roosting places has become common practice in the name of "public health" and "vermin control." With the exception of a follow-up study by Greenhall and Stell (1960), the effectiveness of these compounds for such purposes is virtually unknown. Agencies authorizing the use of pesticides for extermination usually assume that once they have been applied, the vermin have been controlled and the related public health problems resolved. We challenge this assumption.

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BACKGROUND AND METHODS

We studied a colony of little brown bats occupying a barn near Amherst, Hillsborough Co., New Hampshire. The barn
and attached house are over 150 years old, and judging from recollections of former owners, records kept by exterminators, and the appearance of roosts, bats have probably used it for nearly as many years. In the past, numerous attempts were made to exclude bats by sealing potential access routes. According to a local exterminator the interior walls and roost areas of the barn were sprayed with DDT in 1967, and Lindane on subsequent occasions. At these times “numerous” bats were killed, but each year the barn was reinfested.

In 1973 a new owner of the property contacted an exterminator, and 3 sprayings were conducted on 13 and 21 August and “some time in early September” 1973. Reportedly a 2 percent wettable solution of Diazinon (volume unknown) was applied to the interior walls and rafters of the barn on these 3 dates. However, laboratory analyses of crystalline deposits scraped from the walls and roost areas indicate that DDT and chlordane were used (Clark et al. 1978).

We became aware of this bat colony (and the first 2 of the 3 recent applications) on 27 August 1973, when the owner of the property notified us of dead and moribund bats on the floor of the barn. We first visited the colony in early September, soon after the third spraying. We discovered that some of the bats which apparently had been killed during and after the applications of pesticides had been disposed of by the exterminator, and others had been disposed of by the owner and the family cat. Because 2 of the 3 pesticide applications were made in late August and early September, the majority of bats which occupied this barn in the summer of 1973 probably had already departed for transient roosts and swarming sites (Fenton 1969) at the time of spraying. Judging from our studies at other colonies in southern New Hampshire in the same year, we suspect that no more than 10 percent of the maximum 1973 summer population remained at the time of spraying. Thus, the initial pesticide exposure to most residents probably was to residues in the roost the following spring and summer (1974).

On 30 May 1974 we began regular visits to this site at 9 day intervals which continued through mid-September. On each visit in 1974 we trapped bats (Tuttle 1974) as they departed at dusk from a small window-like opening (0.71 x 0.79 m), as they returned from their initial feeding (around midnight), and again before sunrise. Individuals were weighed, sexed, aged (adult vs. young), and reproductive condition was determined. Most were released at the site of capture; those retained were assigned identification numbers, individually packaged, frozen, and later assayed for pesticide residues (Clark et al. 1978). Following evening departures, we recovered all dead and moribund bats lying on the floor and rafters of the barn. In 1975 we also collected dead and moribund bats at 9 day intervals (April through September), and 2 trap samples were taken on 20 July and 15 August as bats departed at dusk.

Forearm measurements of dead and moribund bats were taken in both years and each animal was examined for sex, age, and reproductive condition. No weights were taken because most bats, at the time of collection, were badly decomposed or dehydrated. Where reproductive condition could not be determined for adults at the time of death, we assigned them to the reproductive condition expected for that period. Adults were distinguished from young in having fused phalangeal epiphyses. Ages of juvenile bats (in days) were assigned for the first 3 weeks of post-natal growth, based on extrapolations from the equation for forearm length, \( FA = 37.9 \left(1 - 0.649e^{-0.0109t}\right) \), after Kunz and Hamill (In preparation).
Adult Mortality

The mortality of adults at the time of spraying in 1973 is unknown. However, we suspect that it was minimal since most bats should have migrated before this time. On 30 May 1974, we found 7 female *M. lucifugus* and 8 *Eptesicus fuscus*, all in various stages of decomposition. Most were probably left over from clean-up operations in the previous year. From late May through September 1974 we recovered 23 adult female *M. lucifugus* on the floor of the barn. Of these, 1 was convulsive at the time of recovery (on 27 June). Another bat taken on this date was found in a convulsive state on the ground outside, below an exit. In 1975, 45 adult females were recovered, and of these, 7 (16%) were moribund and convulsing at the time of recovery. Adult mortality in 1975 was nearly twice the 1974 level (Fig. 1B), but we suspect that the true rate of mortality was 3 to 4 times greater since there were fewer bats present in 1975.

The seasonal pattern of mortality for adults differed markedly in the 2 years (Fig. 1B). In 1974 the highest mortality occurred in the lactation period. By contrast, the highest adult mortality in 1975 occurred in the terminal period of gestation and during parturition.

Juvenile Mortality

Seasonal patterns of juvenile mortality also differed markedly in the 2 years of study (Fig. 1C). To clarify these differences, we plotted the frequency of dead and moribund bats in a linear array of size classes (Fig. 2). These data suggest that most of the juvenile mortality occurred during 2 distinctly different periods of maturation, one at or soon after birth and another after they had nearly reached adult size. Accurate age determinations using linear measurements are not reliable after the first

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**RESULTS**

Reproductive Chronology

We estimated that this colony contained a maximum of 500 adult bats in 1974. The reproductive chronology differed from other colonies that we studied in the same year. Although dates of gestation and parturition were within the range of variation at colonies with no history of pesticide application, the lactation period was altered (Fig. 1A) owing to the premature death of nursing young. Whereas 100 percent of adult females were lactating in control colonies from early to mid-July, a maximum of only 75 percent fed young at this time in the treated colony. The remainder of adult females exhibited evidence of mammary gland regression.
3 weeks of age (Kunz and Hamill, In preparation). Therefore, we compared age-specific deaths of young bats only during this 3-week period (Fig. 3). These data show that the highest death rate in the pre-volant period, for both years, occurred in the first 2 days after birth.

In order to include bats older than 3 weeks, we pooled the age-specific data at weekly intervals (Table 1). These results show significant differences in age structure of dead and moribund bats in the 2 years. In 1974, 55 (65%) of the juvenile bats that died in the first week were less than 3 days old, and 65 percent of all young bats died before becoming 3 weeks old. By contrast, in 1975, only 36 percent of young bats died before the age of 3 weeks. More young females than males died in 1974 (Table 2). The sex ratio for *M. lucifugus* at birth is equal (Griffin 1940, Humphrey and Cope 1976); therefore, young females may have been more susceptible to the initial concentrations of pesticides.

We tried to determine the absolute impact of summer mortality on the population density indirectly by comparing the percentages of volant young trapped during emergence periods at the treated colony with similar percentages from a control colony in 1974 (Table 3). Only 26 percent of the bats trapped during emergence at the treated colony were young of the year, whereas the corresponding figure for the control colony was 41 percent. Although we took only 1 comparable sample at the

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Table 1. Age related mortality in juvenile *Myotis lucifugus* after exposure to pesticides. Sexes are combined. The difference in age structure between years is significant ($P < 0.01$).

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>1974</th>
<th>1975</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>1-7</td>
<td>84</td>
<td>42</td>
</tr>
<tr>
<td>8-14</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>15-21</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>&gt;22</td>
<td>71</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 2. Sex ratios of moribund and dead juvenile *Myotis lucifugus* after exposure to pesticides.

<table>
<thead>
<tr>
<th>Year</th>
<th>Males</th>
<th>Females</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>1974</td>
<td>83</td>
<td>41</td>
<td>119</td>
</tr>
<tr>
<td>1975</td>
<td>39</td>
<td>51</td>
<td>37</td>
</tr>
</tbody>
</table>
Table 3. Percentage of volant young *Myotis lucifugus* trapped during initial emergence in the last 2 weeks of July 1974.

<table>
<thead>
<tr>
<th>Treated colony</th>
<th>Control colony³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>No. repro.</td>
</tr>
<tr>
<td>14 July</td>
<td>33</td>
</tr>
<tr>
<td>23 July</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
</tr>
</tbody>
</table>

¹ Carr Colony, located in Peterborough, Hillsborough Co., New Hampshire.

recent colony during the same period in 1975 (20 July, N = 34), the percentage of juveniles trapped (23%) was similar to that taken near the same date in 1974 (Table 3). Judging from flight counts made at the treated colony in 1974 (approximately 500 adults) and an estimated 50 percent reduction in the trappable young (Table 3), we expect that approximately one-half of the young born in 1974 died in the barn from pesticide exposure.

In the first year of our study, mortality among young bats was nearly 9 times greater than that for adults, whereas mortality of young in the second year exceeded that of adults only by a factor of 2. The high mortality of young in 1974 probably accounted for the reduction in total number of adults present in 1975. We suspect that the prolonged period of exposure and residue buildup experienced by the survivors of 1974 (including young and adults) may account for the higher adult mortality in 1975.

**DISCUSSION**

The usual procedure for exterminating bats involves application of dust or wettable pesticide mixtures on interior surfaces of buildings occupied by the target species. Bats that receive pesticides directly have a high probability of death, but because most are out of sight in daytime roosts, few may be hit directly. Instead, bats probably come into contact with toxicants as they crawl over roost surfaces or through small holes during emergence and returns. Other probable routes of intake include inhalation and consumption during grooming. Although the permeability of bat epidermis to pesticides and other compounds is unknown (Quay 1970), they probably are absorbed through the integument. For example, chlordane is readily absorbed through rat skin (Ambrose et al. 1953). Even though ingestion of these compounds during grooming may be highly probable, studies on rats indicate that absorption of chlordane through the skin may have greater toxic effects than oral intake (Ambrose et al. 1953).

We suspect that very young bats are most vulnerable, because in addition to lacking the protection afforded by the pelage, their integument is highly vascularized (Quay 1970). Even if young bats fail to come into direct contact with or inadvertently consume pesticides while grooming, they probably acquire significant quantities in milk (Clark et al. 1978). Pesticide residues have been reported in the milk of rats (Ambrose et al. 1953) and bats (Clark and Lamont 1976a) after having ingested these compounds.

The cumulative effects of pesticides also have long-term implications. Species of bats that undergo annual cycles of fat deposition and withdrawal (Krulin and Sealander 1972) are equally if not more susceptible after fat stores are depleted in late winter and early spring. The fact that chlorinated hydrocarbons are stored in lipids (Ambrose et al. 1953, Luckens 1973) suggests that bats in late summer and early fall may be the least susceptible to toxicological effects, since they are depositing fat stores at these times. Torpor may also increase resistance to neurological and physiological effects of increasing systemic residue concentrations.
during hibernation. Bats may experience severe effects as physiological thresholds for residue concentrations are reached, near the time of arousal from hibernation (Luckens 1973, Clark and Prouty 1976) or during migration (Geluso et al. 1976).

Young bats deposit lipids in the early weeks of growth but subsequently lose these reserves while they learn to fly. This may account for the increased mortality of young as they reach adult size (Fig. 2). The lower mortality observed in the second and third weeks of development could be expected, if during this period lipids are being laid down, and pesticides ingested in mother’s milk are being stored there. Once prolonged feeding flights occur, fat would be mobilized, leading to increased residue levels in the brain, resulting in death. On those occasions when we observed moribund animals, they experienced convulsive tremors characteristic of events leading to death from pesticide poisoning: DDT (Luckens and Davis 1964, Jefferies 1972), dieldrin and endrin (Luckens and Davis 1965), chlordane (Ambrose et al. 1953).

Natural mortality in adult and young M. lucifugus in summer nursery colonies is negligible (Humphrey and Cope 1976, Unpublished data). We seldom found more than 1 or 2 dead individuals in colonies where there was no history of pesticide application or excessive human disturbance. The colony reported here is truly an exception, and the evidence indicates that the high death rate and prolonged mortality observed can be directly attributed to the effects of pesticide poisoning (Clark et al. 1978).

Public Health Implications

The principal justification cited by federal agencies in granting exemptions for use of highly toxic pesticides in bat control is that it is the only effective method (Greenhall and Stell 1960) in spite of evidence to the contrary (Laidlow and Fenton 1971). In the majority of New England DDT exemptions cited in the U.S. Federal Register, no documented evidence exists for serious public health hazards from bats. Attempts are made to exterminate these animals following the erroneous assumption that bat rabies is “endemic” to a region (see Federal Register 1974-20185). In the only documented study on the incidence of rabies in New England bats (Girard et al. 1965), less than 2 percent of a random sample of bats were rabid. For M. lucifugus the incidence was less than 1 percent and for Eptesicus fuscus it was somewhat higher (4.1%). Whether or not clinical diagnosis of rabies has been demonstrated in a colony, the physiological stress imposed by sublethal levels of pesticide toxicity may activate latent viral infections (Debbie 1974), thereby increasing the incidence of rabies (C. V. Trimarchi, Personal communication). That such a possibility exists is supported by studies showing that corticosteroids interfere with a host’s defense system against this and other viruses (Enright et al. 1970).

Although public health officials continue to seek exemptions for use of pesticides in bat control, exterminators and public health personnel have not reported the effects of such applications. Our data suggest that this situation increases, rather than eliminates, potential health hazards to humans. Since moribund bats often fall to the floor of buildings and into yards following the application of pesticides, the probability of human contact is increased. Pets and small children are more likely to encounter these animals at least 2 years after initial pesticide applications.

While we cautiously support the view that bats should be exterminated in cases where an outbreak of rabies (demonstrably high prevalence of infection) is documented, we strongly oppose the practice of
applying pesticides for bat control. If chemical control is used, follow-up studies must be undertaken by qualified personnel to insure that short and long-term risks of human exposure to bats (as well as to the chemical) have not been increased. We believe that a need exists to educate the public toward a climate that recognizes the inescapability of, and desirability of, coexistence of man and bats.

LITERATURE CITED


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Note added in proof:
Persistent bat mortality is evident in this colony, now into the fourth year after the last pesticide application.