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Factors influencing estimation of pesticide-related wildlife mortality

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Free-ranging wildlife is regularly exposed to pesticides and can serve as a sentinel for human and environmental health. Therefore a comprehensive pesticide hazard assessment must incorporate the effects of actual applications on free-ranging wildlife. Mortality is the most readily reported wildlife effect, and the significance of these data can be realized only when placed in context with the factors that affect the gathering of this type of information. This paper reviews the variables that affect the collection of wildlife mortality data. Data show that most effects on wildlife are not observed, and much of observed mortality is not reported. Delays in reporting or in the response to a report and exposure to multiple stressors distort the exposure–effect relationship and can result in uncertainty in determining the cause of death. The synthesis of information strongly indicates that the actual number of affected animals exceeds the number recovered.

Keywords: *confirmation, detection, hazard assessment, mortality, pesticides, reporting, wildlife.*

Introduction

Pesticides are a unique group of compounds in that their purposeful release into the environment is considered beneficial, despite their possible adverse effect on the environment. This distinguishing characteristic is obviated by referring to their release as 'application' or 'treatment'. Pesticides are synthesized to be poisonous, yet most of these compounds are broad-spectrum, and their applications can result in unintentional ecological damage. This benefit–hazard nature of pesticides propels them into regulatory scrutiny. In the United States, the Environmental Protection Agency (EPA) conducts hazard–benefit analysis in support of pesticide registrations under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). A pesticide is registered for use if, "when used in accordance with widespread and commonly recognized practice, the product will not generally cause unreasonable adverse effects on the environment" [FIFRA Section 3(c)(5)] (US EPA, 1988). To determine if a pesticide meets this requirement, a comprehensive hazard assessment must incorporate the effects of actual applications on free-ranging wildlife.

The success of field data collection depends on how readily an adverse effect can be detected. An observer is more likely to detect an adverse effect when discovering a mortality event than when coming across a biochemically disrupted animal with no overt signs of stress. Furthermore, the definitive nature of mortality requires no speculation about the consequences of the effect to the organism. Therefore, mortality is the most readily reported pesticide effect on wildlife (Smith, 1987; US EPA, 1998) and is also one of the primary endpoints used by the EPA in its hazard assessments. The significance of mortality data can be realized only when placed in context with the factors that affect the gathering of this type of information. Contemporary-use pesticides to which wildlife mortality is most commonly attributed in the United States are the organophosphorus (OP) and carbamate (CB) insecticides. This paper reviews the variables that affect the collection of ecological effects data, specifically, wildlife mortality from OP and CB insecticides.

Observing the effects

A major obstacle to gathering information on field effects is that such events may be difficult to detect. Strong evidence from laboratory trials, field studies, monitoring, and site-investigations illustrates how an obvious adverse effect such as mortality can remain undetected. On a landscape level, effects may be overlooked because of the vastness of the areas subject to pesticides and the spatiotemporal mosaic of the pesticide applications. Pesticides are used on field crops, fruits, vegetables, forests, turf and lawns, and ornamentals. The area involved renders it impossible to monitor for all wildlife effects. This situation is complicated further by inaccessibility to private property.

1. Abbreviations: CB, carbamate; EPA, Environmental Protection Agency; FIFRA, Federal Insecticide, Fungicide and Rodenticide Act; OP, organophosphorus

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On the local scale, mortalities also may go undiscovered. The initial discovery of a carcass and subsequent search for more are moderated by several biological and anthropogenic variables. These include scavenger and predator populations, animal behavior, carcass morphology, habitat type, and search intensity. These factors may vary spatially and temporally, but are common to all mortality events.

Scavengers and predators exert considerable pressure on a carcass population. Many of these carcasses are removed from the site and are unaccounted for in searches. Balcomb (1986) placed 78 carcasses representing four songbird species in 23 corn fields. Results of seven trials revealed that 62–92% of the carcasses were scavenged within 24 h of placement. A similar experiment by Wobeser and Wobeser (1992) involving the placement of day-old chick carcasses in a pasture at a density of 50 birds/ha resulted in scavenging on 76% of the carcasses within 24 h. Additional studies have shown that the rate of scavenging within 24 h of carcass placement can range from 0–62%, depending on the habitat (Mineau and Collins, 1988). Stutzenbaker et al. (1983) demonstrated that low-density die-offs are difficult to detect and that carcasses are most likely to be found in a large-scale die-off where the number of animals that died exceed the capabilities of predators and scavengers to remove them. Scavengers and predators may modify their behaviors to exploit a pesticide-affected prey population. Linz et al. (1991) found that carcass removal by scavengers was more rapid in areas of higher carcass density than in lower density kills because the clumped food source may strongly attract scavengers. Similar observations were reported for pied kingfishers (*Ceryle rudis*) attracted to fish kills following applications of the organochlorine insecticide endosulfan (Douthwaite, 1982). Birds fed faster and spent more time in areas of fish kills than in pre-application observations (Douthwaite, 1982). Furthermore, sublethally exposed animals may also disappear from the site because they may be more susceptible to predation. House sparrows (*Passer domesticus*) and northern bobwhites (*Colinus virginianus*) exposed to the OP insecticides fenthion and methyl parathion were captured more frequently by predators than their conspecific controls (Galindo et al., 1985; Hunt et al., 1992). Field observations by Buerger et al. (1991) and Hawkes et al. (1996) reported that free-ranging northern bobwhites dosed with methyl parathion were subjected to greater predation than birds not dosed.

Poisoned wildlife may attempt to seek cover to escape predation and inclement weather (Mineau and Peakall, 1987; Busby et al., 1990; Fryday et al., 1996). Fryday et al. (1996) observed that seven of nine European starlings (*Sturnus vulgaris*) dosed with the OP insecticide chlorfenvinphos immediately flew into a cover of artificial vegetation, and the two remaining birds, which were unable to fly, walked to the cover. Carcasses of starlings that subsequently died were retrieved from beneath the cover. This behavior has also been recorded in the field. Observations on free-flying white-throated sparrows (*Zonotrichia albicollis*) by Busby et al. (1990) described the birds making short, erratic flights and seeking dense cover following forest applications of the OP insecticide fenitrothion. Cover-seeking can cause a carcass to go unnoticed during a search. Consequences of this behavior are demonstrated by a searcher-efficiency trial (conducted 30 min post-carcass placement to minimize scavenging) that recovered none of the 50 ducks placed in typical escape cover, but located six of 50 birds placed atop vegetation (Stutzenbaker et al., 1983).

Poisoned wildlife not actively seeking cover can also be difficult to locate by human searchers because of their morphology and ground-vegetation composition. Searchers are more likely to find large, brightly colored animals than those that are small and cryptically colored. A carcass-detection trial by James and Haak (1979) resulted in the recovery of 80% of the rock doves (*Columbia livia*) and European starlings and 30% of the smaller, drabber house sparrows. A similar bias towards colorful individuals was observed by Linz et al. (1991), in which more carcasses of male red-winged blackbirds (*Agelaius phoeniceus*) were found than those of females. A survey of wildlife mortality events in Virginia revealed that incidental detection of bird kills in remote areas (*e.g.*, agricultural fields) involved either large birds or large numbers of small birds. [1] Vegetative structure can reduce searcher success by camouflaging the carcass or blocking the searcher's line of sight. Stinson et al. (1994) reported that searchers encountered more evidence of affected wildlife on tilled fields with no vegetative cover than on no-till fields with dense stands of wheat and rye. Similarly, Tobin and Dolbeer (1990) discovered that the lowest percentage of carcass recovery in their study occurred in an orchard with the heaviest ground cover. The interaction between morphology and ground-vegetation type is demonstrated by Philibert et al. (1993): their searches recovered significantly more of the larger and colorful meadowlark models than the smaller, duller sparrow models in an ungrazed pasture and a short-grass prairie, but located significantly fewer bird models in the pasture than in the prairie habitat. The mean carcass-detection distance was also significantly less in pastures than in prairies.

Carcass recovery is further biased by search intensity, which in turn, is affected by the type of contaminant, route of exposure, natural history of the poisoned species, and

[1] Personal communication: E. Stinson, Virginia Department of Game and Inland Fisheries.

experience level of the searchers. OP and CB insecticides have similar modes of action but may (depending on chemical and exposure) manifest different mortality patterns. Dietary toxicity experiments have shown that birds that die from CB insecticides do so within a few hours of exposure but mortality from OP insecticide exposure may extend over 5 days (Hill, 1992). Chemical, application method, pesticide formulation, and wildlife species may affect the importance of the different exposure routes (inhalation, dermal, and ingestion from food, water, or preening), which in turn may modulate rate of death (Driver et al., 1991). In the above cases, a limited carcass search, as is often the case because of limited resources, may miss animals that have moved out of the area, and an individual animal found dead away from the treated area may not be associated with an insecticide application.

The influence of the natural history of the poisoned species on search intensity encompasses factors such as physiology, life cycle, and behavior. Laboratory and field studies show adult songbirds to be 2 to 137 times less sensitive to OP insecticides than their nestlings (Grue and Shipley, 1984; Wolfe and Kendall, 1998). Mortality investigations typically do not extend to nests and burrows, primarily because of limited resources. Since the initial discovery of a mortality event usually depends on finding dead or moribund adults, the young may have died in the nest before the adults were affected and subsequent evidence of the kill was observed. A study on the effects of the OP insecticide diazinon on breeding songbirds in Christmas tree plantations found no adult mortalities, but reported twice as many cases of total mortalities for American robin (*Turdus migratorius*) and song sparrow (*Melospiza melodia*) nestlings, when compared to control nests (Rondeau and Desgranges, 1995).

Predators that maintain large breeding territories [*e.g.*, average home range of breeding Swainson's hawks (*Buteo swainsoni*) covers 27.3 km^2; Andersen, 1995] may scavenge at a pesticide kill, but deliver the poisoned item to their nestlings. Raptors may also carry their prey to a tree or woodland edge, which may be located several kilometers away, before consuming it.[2] In both cases, the location of the raptor poisoning may lie outside the perimeter of a carcass search.

Search intensity can also be decreased if the individuals responding to a mortality report are inexperienced searchers. A carcass placement study by Heijis (referred to in Linz et al., 1991) demonstrated that novice searchers missed 28–38% more carcasses than veteran searchers. The importance of experience was also illustrated by a study where search success for cryptically colored carcasses increased significantly with succeeding trials (Linz et al., 1991).

Reporting the effects

Many mortality events are serendipitous finds by the public (*e.g.*, a jogger coming across a carcass). The level of human activity affects the discovery of a die-off. Stinson tabulated that 72% of the carbofuran mortality cases in Virginia were discovered in areas of frequent human activity (golf courses, work sites, yards, roadsides, and piers), while 12% of the cases were located in areas of lower activity (fallow fields, pasture, crop fields, and woodlots).[1] Once a dead animal is observed, it must be reported to appropriate state and federal wildlife authorities so that a systematic carcass search and sample collection can be conducted. Reporting, however, is hampered by public ignorance that the kill should be reported and to whom it should be reported, as well as apathy, procrastination, and fear of prosecution. A mortality event may also go unreported when an observer finds only one or two carcasses and attributes it to natural mortality. Such people may consider it absurd to report the finding.[3]

Confirming the effects

Report of a mortality event to the appropriate authorities may initiate an investigation to document the event. The investigation involves collection of carcasses and other samples (*e.g.*, soil, vegetation, *etc.*), interviews with the applicators and associated individuals, and laboratory analysis for biomarkers and pesticide residues to determine cause of death. Unless part of an organized field study or monitoring search, immediate response to a mortality report may involve only one or two wildlife personnel. Immediate response may not always be possible because of the distance, terrain, weather, private property issues, and on-going investigations.[2] Wildlife mortality may be scattered in a field's interior, along its perimeter, and across the surrounding area and may require many resources to investigate (Blus et al., 1989; Stinson et al., 1994). Inadequate number of personnel results in a limited search area and an increased interval between the time of the poisoning and collection of carcasses.

An increasing interval between the mortality event and carcass collection reduces the chances of salvaging carcasses suitable for laboratory analysis. Hill and Fleming (1982) determined that the duration and environmental

[2] Personal communication: D. Fries, US Fish and Wildlife Service.

[3] Personal communication: D. Patterson, US Fish and Wildlife Service.

conditions of the interval may confound the interpretation of brain cholinesterase activity measurements, the key biomarker for determining OP and CB insecticide exposure and effect. The interval also increases the chances of carcass scavenging and putrefaction. Depending on the magnitude of the kill and the scavenger population, even a short interval may result in poor carcass recoveries. White et al. (1990) studied the survival of free-living northern bobwhites in croplands subject to OP and CB insecticide applications. Despite intensive radio-telemetric monitoring to locate the carcasses, the researchers were not able to determine the cause of mortality for any of the birds because scavenging rendered the carcasses unsuitable for necropsy and pesticide analysis.

Carcass decomposition rates depend on carcass size, temperature, humidity, rainfall, and insect density and diversity (Tullis and Goff, 1987). Complete decomposition of a bald eagle (*Haliaeetus leucocephalus*) carcass (except bones, feathers, beak, and feet) found next to a carbofuran-treated field was determined to have occurred within 3 days. [3] During field trails with the avicide 4-aminopyridine, Woronecki et al. (1979) could not determine cause of death for 24 of 26 carcasses because of their deteriorated condition. In the above kills, carcasses were recovered, but the cause of death could not be confirmed, and can only be considered circumstantial evidence of poisoning.

Delayed mortalities resulting from sublethal and indirect pesticide effects further obfuscate the exposure–effect relationship and consequently the magnitude of the die-off. For example, a pesticide-intoxicated bird that is struck by a car because it is too uncoordinated to maneuver around the oncoming vehicle may be counted as a roadkill and not a pesticide-related mortality. Some sublethal effects of OP and CB insecticides that may affect survival include territory abandonment and reduced parental care (Grue et al., 1982; Busby et al., 1990; Millikin and Smith, 1990), increased likelihood of predation (Galindo et al., 1985; Fairbrother et al., 1988; Buerger et al., 1991; Hunt et al., 1992), reduced food-begging behavior by nestlings (Grue and Shipley, 1984), decreased learning and memory (Kreitzer and Fleming, 1988), migratory disorientation (Vyas et al., 1995), and reduced tolerance to cold (Fleming et al., 1985). Indirect effects of pesticides include nestling mortality and malnutrition due to parental inattentiveness and mortality (Bart and Tornes, 1989). Death and malnutrition may also be an indirect manifestation of pesticide-induced food depletion for insectivorous animals (Douthwaite, 1986; Potts, 1990; Rodenhouse and Holmes, 1992; Sample et al., 1993; Whitmore et al., 1993). Herbicide use has been demonstrated to alter the nesting habitat of the Brewer's sparrow (*Spizella breweri*) and therefore may affect their survival indirectly (Schroeder and Sturges, 1975). Reduction in food and suitable habitat may increase competition for territories and consequently increase the stress on a population.

Discussion

Wildlife is regularly exposed to pesticides. Incidental mortality reports confirm the hazard of these chemicals from actual use, however, the magnitude of the effects is not known. The mortality pyramid can be used to summarize this review (Figure 1). The figure is a generic representation because tier sizes would vary by kill. In light of the evidence presented, the bottom tier would envelop the pyramid for most of the die-offs.

The majority of the effects on wildlife are not observed. Geographic, biological, and anthropogenic factors influence the successful detection of affected wildlife on the landscape and local levels. Much of the observed mortality is not reported, possibly due to ignorance, apathy, procrastination, or fear. Delays in reporting or in the response to a report can result in uncertainty in determining the cause of death. Exposure to multiple stressors and the lack of data on the toxicity of mixtures further complicate the confirmation of cause of death. The tip of the pyramid is characterized by mortality events that have been observed, reported, and confirmed. This smallest of the subsets in the mortality pyramid represents our current knowledge of the effects of pesticides on free-ranging wildlife. It is difficult to relate this subset to the bottom tier of the pyramid to estimate the actual wildlife loss because of the variables described in this report. However, the appreciation of the three lower tiers authenticates the value of this data set. The weight of evidence generated by the top level is considerable, for on the landscape level, it strongly implies the possibility that adverse effects from a particular pesti-

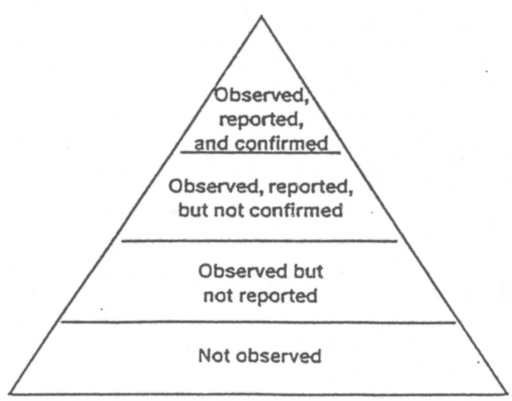

Figure 1. Generic relationship between actual wildlife mortalities and the current information of the events. Most wildlife mortality is unaccounted for and the top tier of the pyramid is characterized by mortality events that have been observed, reported, and confirmed. This level of the pyramid represents our current knowledge of pesticide effects on free-ranging wildlife. Size of tiers will vary by kill.

cide use may occur commonly. On the local level the data unequivocally state that the actual number of affected animals per mortality event typically exceeds the number recovered.

Wildlife mortality records form an integral part of hazard assessments for human and environmental health. This information is critical to the EPA for conducting hazard assessments on ecological and human health because it illustrates actual-use effects. Data are useful to state and federal wildlife officials for monitoring pesticide kills, especially for endangered and threatened species. Collection of these reports also enables them to determine if a new pesticide proposed for use in their region has resulted in ecological harm elsewhere. An intensive monitoring effort by Stinson et al. (1994) found evidence of affected wildlife on 33 of 44 carbofuran-applied agricultural fields in Virginia. Her high success rate is partially due to the chemical involved and the monitoring design, but it demonstrates the pervasive nature of pesticide-related wildlife mortality. Therefore, the current paucity of the information on the effects of pesticides to wildlife strongly reflects an inadequate monitoring and reporting system. Efforts must be made to improve the detection and reporting of these events by (a) enhancing public awareness and education to increase detection and reporting of effects, (b) providing additional support to wildlife personnel to increase their search intensity, (c) improving forensic methods for determining cause of death, (d) developing and supporting national and global databases to centralize the information, and (e) making this information available to the public.

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