The IPM Paradigm: Vertebrates, Economics, and Uncertainty

Ray T. Sterner
USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado

ABSTRACT: The concepts of "integrated control" and "integrated pest management" (IPM) were devised by entomologists, but they proved relevant to the monitoring and control of virtually any agricultural pest (i.e., weeds, fungi, vertebrates). Within IPM, economic threshold characterized pest densities that would have negative impacts and economic injury level characterized amounts of predicted crop injury (destruction) that would allow recovery of potential pest-control costs. Approximately 150 species or groups of vertebrates have been documented to pose human health/safety risks or to cause agricultural, natural resource, and property losses in North America. Rodent (e.g., mice, rats, ground squirrels) and bird (e.g., blackbirds, gulls, cormorants) populations are the most frequently cited species/groups of vertebrates linked with IPM. Uncertainty characterizes IPM applications to control damage by these species/groups. Uncertainty is a measure of variance, which occurs due to the myriad of biological, crop, economic, meteorological, pesticide, production, seasonal, and soil unknowns that impact IPM programs. Six uncertainty-reduction techniques are commonly used by economists: 1) worst-/best-case scenario, 2) contrived scenarios, 3) decision tree analysis, 4) sensitivity analysis, 5) Monte Carlo simulation, and 6) systematic projections. This paper reviews key IPM literature, especially economic literature, and discusses techniques that can reduce the economic uncertainty of using IPM programs with vertebrates.

KEY WORDS: agriculture, benefit-cost, economics, integrated pest management, IPM, wildlife damage

INTRODUCTION

Integrated pest management (IPM) refers to the systematic, repeated application of pest-monitoring and -control technology to reduce the economic impacts of diverse insects, pathogens, nematodes, weeds, and vertebrates that damage agriculture (Cate and Hinkle 1994, Kogan 1998). From the outset, economics played a key role in IPM (Stern et al. 1959). Economic threshold (ET) described the lowest pest density that correlated with economic loss at harvest and economic injury level (EIL) referred to the amount of damage that afforded recovery of monetary expenses paid for control (Stern 1973, Pedigo and Higley 1997). In IPM economics, injury differs from damage (Pedigo and Higley 1997). Injury refers to lowered production due to pests, whereas damage refers to the monetary loss based on that injury. Granted, some confusion surrounded the early definitions and computational formulas for ET and EIL, but persistent refinement of these concepts and formulas has led to useful quantifications (Pedigo and Higley 1997).

The IPM concept was developed largely by entomologists in the 1950s and 1960s, with the use of insecticides to control crop loss a priority (Kogan 1998). Later, during the 1970s, extensive reliance on chemical pesticides was viewed as the bane of IPM, as insecticide resistance in insects and public concerns about the environment occurred (Carlson 1962, Cate and Hinkle 1994). While extensive literature describes pest-monitoring and -control programs for insects (e.g., Stern et al. 1959, Pedigo and Higley 1997, Kogan 1998), relatively few long-term IPM programs to reduce agricultural, natural resources, and property damages, or to lower public health/safety risks caused by vertebrates, exist (e.g., Ramsey and Wilson 2000, Linz 2003, Witmer 2007, U.S. General Accounting Office 1990).

Here, I review selected literature relevant to IPM for vertebrates. Specifically, the paper 1) reviews the IPM chronology and paradigm, 2) identifies North American species or groups of vertebrates documented to pose human health/safety risks or to damage agriculture, natural resources, and property, 3) describes key concepts involved in IPM economics as well as procedures that can reduce the economic uncertainty of vertebrate IPM programs, and 4) discusses several current issues affecting IPM programs with vertebrates.

IPM CHRONOLOGY

The chronology of IPM spans ≈50 years. Detailed time lines of major milestones have been published (e.g., Cate and Hinkle 1994, National Research Council 1996). Founding concepts were developed during the late 1950s at the University of California at Berkeley, where a group of scientists introduced the concept of "integrated control" for agricultural pests (Stern et al. 1959). Integrated control referred to the intense use of insecticides to reduce insect populations over large areas, thereby decreasing crop losses (Stern et al. 1959). Ten years later, scientists focused on key pest species and used the term IPM to convey the idea that routine pest-monitoring and pest-control were needed to time control applications and to provide long-term crop protection via maintenance of pest densities or populations at tolerable levels (Smith and van den Bosch 1967). In the 1970s, use of the term agro-ecosystem reflected the ecological perspective of these scientists toward the scale of pest species interactions and management related to IPM (Kogan 1986, National Research Council 1996). Reliance on insecticides, herbicides, fungicides, and other pesticides was de-emphasized, while more emphasis was placed upon the use of biological methodologies (Council on Environmental Quality 1972). The greater reliance on pest monitoring, the timing of pest-control applications, and the use of biological controls made IPM programs more efficient (Kogan 1986, Cate and Hinkle 1994).

194

Managing pest habitats and controlling the seasonal reproductive cycles of key species were considered salient to preventing pest-caused losses (Kogan 1986). In the 1990s, IPM received renewed emphasis, with the Clinton administration's unmet goal that 75% of U.S. cropland be farmed using IPM by the year 2000 (U.S. General Accounting Office 2001, Fitzner 2002).
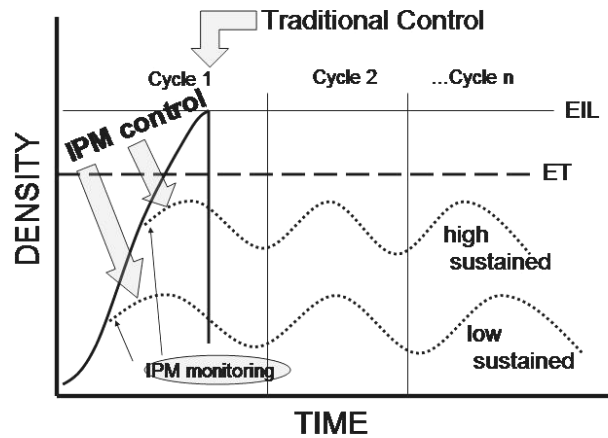
IPM PARADIGM

The IPM paradigm can be viewed as a temporal pattern of pest-monitoring and -control activities often involving national, regional, and state support (Allen and Bath 1980). Essentially, the seasonality of crops and pests leads to fluctuations in pest populations, habitats, forage, and potential population growth, which allow for timely intervention with control methodologies to reduce pest densities/populations to levels associated with tolerable crop or resource losses.

The application(s) of pest-control methods are linked to a pest density or population index. Surveillance affords prediction of density and population growth, which allows intervention to prevent (e.g., repel, harass, depopulate) pest build ups– an action threshold (Alston 1996). Pest-monitoring and -control (both annually and during crop cycles) are key elements of any IPM paradigm (Figure 1). Low or high sustained density of mature pests, fecundity, available forage, and meteorological conditions during crop dormancy or inter-crop cycles, coupled with precipitation and potential vegetative-growth or prey-base factors, interact to determine the frequency of pest-monitoring events. The size of these sustained pest populations impacts potential benefits and costs. Persistence of pest populations affects monitoring frequencies, efficacy of control technologies, and potential economic savings. The frequency of monitoring and control activities needed to effectively lower crop/resource injury or damage affects both the cost outlays of IPM and the potential savings to be recouped by pest-control activities. Prevented damages become potential savings.

Intervention decision-making based on pest indices has become a main feature of IPM programs (Duffy 1997, Sterner 2002). Pest-monitoring and -control costs are dispensed over time, and pest population density or size (i.e., as monitored) triggers the control application(s). Farmers, extension agents, and researchers need to decide on the population density that will be tolerated in an area. The use of more or less efficacious control technologies will be reflected in the benefits and costs of the IPM scheme– more frequent, less effective control or less frequent, more effective control will impact application decisions and returns on investments.

VERTEBRATE PESTS

The historical focus of IPM upon insect damage is not surprising. Insects comprise the bulk of the Earth's species, cause considerable damage to crops, and are readily monitored (i.e., water traps, sticky papers) and controlled via insecticides (Kogan 1998, U.S. General Accounting Office 2001, International Union for Conservation of Nature and Natural Resources 2007).

Figure 1. Schematic of the IPM paradigm showing plots of theoretical pest densities and pest-monitoring and -control timing to maintain high and low sustained populations below the ET and EIL. (Note: only a single monitoring and control activity is shown; the paradigm assumes that control is applied before peak pest densities and that multiple monitoring and control events occur over successive crop cycles and years.)

Conversely, vertebrates comprise a relatively small subset of the world's species, with only a portion of these linked with crop damage and even fewer that lend themselves to wide-area, labor-intensive, annual indexing techniques (e.g., snap traps, pesticides), and control applications (see White et al. 1982, Hygnstrom et al. 1994, Ramsey and Wilson 2000, Anderson 2001, White and Lubow 2002, Engeman 2003, Linz 2003, Witmer 2007). Whereas insects can be controlled efficiently with chemicals, vertebrates may require a host of diverse management techniques (e.g., Sherman traps, chemical pesticides, repellents, calling and shooting).

Of the 1,589,361 species described in 2007 by the International Union for Conservation of Nature and Natural Resources, invertebrates (e.g., insects, mollusks, crustaceans, corals, and others) comprised 1,203,375 and vertebrates (i.e., mammals, birds, reptiles, amphibians, and fishes) comprised 59,811 of these organisms (IUCN 2007). Thus, invertebrates comprised 76% and vertebrates comprised 4% of Earth's described species. Furthermore, 950,000 (60%) of species were classified as insects, whereas, only 9,956 (0.6%) and 5,416 (0.3%) of species were birds and mammals, respectively (IUCN 2007).

Although generating any list of vertebrate pests is tenuous, only a limited number of vertebrate species (or groups) are documented to pose human health/safety risks or to damage agriculture, property, natural resources (see Table 1). A well-known vertebrate pest control manual lists 82 species or groups of vertebrates as warranting description of pest management methods; this includes 29 rodent, 16 carnivore, 11 other mammal, 8 reptile and amphibian, and 18 bird species or groups (see Hygnstrom et al. 1994). Additionally, a review of literature dealing with birds, agricultural damage, and aviation hazards

Table 1. Common names of selected vertebrate groups or species linked with North American agriculture, natural resource, and property damage and public health/safety risks.

Mammals, Reptiles and Amphibians (see Hygnstrom et al. 1994)		
Alligator	Elk	Rat (>1 species)
Armadillo	Pig (feral)*	River Otter
Antelope	Frog and Toad (>1 species)	Salamander (>1 species)
Badger	Fox (>1 species)	Shrew (>1 species)
Bat (>1 species)	Ground Squirrel (>1 species)	Skunk (>1 species)
Bears (>1 species)	Jackrabbit (>1 species)	Snake (>1 species)
Beaver	Mouse (>1 species)	Tree Squirrel (>1 species)
Bobcat	Mink	Turtle (>1 species)
Cat (feral)	Mole	Vole (>1 species)
Chipmunks (>1 species)	Mountain Lion	Weasel (>1 species)
Coyote	Nutria*	Woodrat (>1 species)
Crayfish	Opossum	Wolf (>1 species)
Deer (>1 species)	Pocket Gopher (>1 species)	
Dog (feral)	Raccoon	

Birds (see Sterner et al. 1984)		
Acorn Woodpecker	European Starling*	Red-shafted Flicker
American Crow	Field Sparrow	Red-winged Blackbird
American Goldfinch	Franklin's Gull	Ring-billed Gull
American Robin	Fulvous Whistling Duck	Ringed-necked Pheasant
American Widgeon	Golden-crowned Sparrow	Rock Dove
Barn Swallow	Gray Catbird	Rose-breasted Grosbeak
Black-capped Chickadee	Green-winged Teal	Rufous-sided Towhee
Black-billed Magpie	Great-tailed Grackle	Rusty Blackbird
Blue Grosbeak	Horned Lark	Sandhill Crane
Blue Jay	House Finch	Savannah Sparrow
Blue-winged Teal	House Sparrow	Scarlet Tanager
Boat-tailed Grackle	Indigo Bunting	Scrub Jay
Bobolink	Lewis Woodpecker	Song Sparrow
Brewer's Blackbird	Mallard	Tri-colored Blackbird
Brown-headed Cowbird	Mottled Duck	Western Bluebird
Brown Thrasher	Mourning Dove	Western Kingbird
California Quail	Northern Bobwhite	Western Meadowlark
Canada Goose	Northern Cardinal	Western Tanager
Cattle Egret	Northern Mockingbird	Wild Turkey
Common Grackle	Northern Oriole	White-crowned Sparrow
Cedar Waxwing	Northern Pintail	White-winged Dove
Dickcissel	Northern Raven	White Pelican**
Double-crested Cormorant**	Orchard Oriole	Yellow-billed Magpie
Eastern Bluebird	Pine Siskin	Yellow-headed Blackbird
Eastern Meadowlark	Red-headed Woodpecker	Yellow-shafted Flicker

* considered invasive   ** added after original review

found that 75 species were documented in published literature as causing agricultural or aviation-related damage (Sterner et al. 1984).

In short, IPM strategies imply predictable amounts of damage, based on population size or density of the pest species. Low densities of many carnivores or certain animals, coupled with the localized, sporadic damage typically caused, do not always make IPM for these carnivores or animals economically efficient (e.g., livestock predation by a rogue bear, pet predation by a mountain lion, mower blade damage by a few mounds of remaining pocket gophers). For example, the relatively long lifespan of pocket gophers (*Geomys* or *Thomomys*) makes even a few of these animals a risk to farmers that should be addressed for economical farm operation– ET = 0 (see Marsh 1981). Analogously, costs to prevent a rare, single, "rogue" event by a carnivore would occur as a *post hoc* outlay– preventative use of IPM to control this type of predation *a priori* would be inefficient use of rancher monies, since prediction would be remote or impossible. For such reasons, rodent (e.g., mice, rats, ground squirrels) and bird (e.g., blackbirds, gulls, cormorants) populations are the most frequently cited species/groups linked with IPM schemes (Ramsey and Wilson 2000, Linz 2003). Of course, human-wildlife conflicts are dynamic, and traditional or new species can become involved or disassociated with damage as farm practice, human development, or wildlife populations change. Papers included within these Proceedings describe marine mammal (i.e., sea lion, harbor seal) impacts on sport fishing and nuisance or property damage at docks in the San Diego Harbor (see Fletcher 2008, DeAngelis and Curry 2008).

VERTEBRATE IPM ECONOMICS

As stated, confusion and misuse have plagued the terms ET and EIL since their inception. Currently, ET refers to the lowest pest density (e.g., number/leaf, number/ha) associated with economic damage to a specific farming activity, crop or commodity (Alston 1996, Pedigo and Higley 1997). Action threshold (AT) has somewhat replaced ET and is defined as the lowest pest density at which pest control should be started– a decision point to recoup expenditures (Alston 1996). The term EIL has come to refer to the amount of pest-caused injury that justifies pest-control expenditures (Higley and Pedigo 1997). Thus, EIL is now viewed from a benefit-cost perspective– the damage value at which savings (benefits) would equal or exceed the costs of control applications (Pedigo and Higley 1997). The common EIL equation today is:

$$EIL = C / (V \bullet D \bullet I \bullet K)$$

where EIL is injury per production unit (e.g., insects/ha), C is pest-control and -monitoring costs per production unit (e.g., $/ha), V is market value of crop, resource, etc. per production unit (e.g., $/kg), D is damage per unit injury (e.g., kg reduction/ha/injury), I is the level of injury per pest (e.g., g/pest), and K is the proportional reduction in injury with IPM in effect) (Pedigo and Higley 1997).

Recently, this formula was adapted to vertebrate IPM schemes (Sterner 2002, 2008). Essentially, this modification entailed a formula derivation based on typical pest-monitoring and -control procedures for vertebrate populations, coupled with typical agricultural valuations. Key equations (Eq.) are:

$$V_{max} = Y \bullet P \bullet A \qquad \text{(Eq. 1)}$$

where Y is crop yield (production/unit), P is price (US$ • production/unit), and A is the area considered in the agro-ecosystem or production (ha). (This provides a total value.)

$$S_{max'} = V_{max} \bullet D \qquad \text{(Eq. 2)}$$

where V_{max} is defined in Equation 1 and D is the amount of vertebrate pest damage (%). (This provides the estimate of maximum savings that can result in a vertebrate pest damage situation.)

$$C_{sur} = (C_p \bullet M) + [(C_{ma} \bullet Q) + (C_{mb} \bullet Q) + ... (C_{mx} \bullet Q)] \qquad \text{(Eq. 3)}$$

where C_p is the labor cost ($US), M is the number of monitoring events, C_m is the combined material cost ($US) represented by $C_{ma}, C_{mb}, ... C_{mx}$ types of equipment or supplies and Q is quantity. (This estimates the pest-monitoring costs.)

$$C_{app} = (C_{p1} \bullet A) + (C_{m1} \bullet A) \qquad \text{(Eq. 4)}$$

where C_{p1} is the labor cost ($US/ha), C_{m1} is the materials cost ($US/ha), and A is area (ha) as defined in Equation 1 (This estimates the pest-control costs.)

$$S_{net'} = (S_{max'} \bullet E) - (C_{sur} + C_{app}) \qquad \text{(Eq. 5)}$$

where $S_{max'}$ is defined in Equation 2, E is the projected effectiveness of the IPM monitoring and pest control written as a simple percentage (%) or decimal (0.00), and C_{sur} and C_{app} are defined in Equation 4. (This is the estimate of savings based upon an assumed efficacy.)

Finally, a benefit: cost ratio (BCR) is computed. This ratio indicates that savings are smaller (IF < 1.0) or equal to or larger (IF ≥ 1.0) than the IPM costs. This ratio is descriptive of relative costs and savings; it is constant across areas (ha):

$$BCR = [S_{max'}/(C_{sur} + C_{app})] + 1 \qquad \text{(Eq. 6)}$$

UNCERTAINTY REDUCTION

Uncertainty is a measure of variance, which fluctuates due to the myriad of biological (e.g., pest population density, larvae hatch duration), crop (e.g., drought tolerance, compensatory growth), economic (e.g., market price, pest damages), meteorological (e.g., minimum nighttime temperature, hail occurrence), pesticide (e.g., spray drift, crop leaf distribution), production (e.g., seed voids, plant root depth), seasonal (e.g., last frost, average dew point), and soil (e.g., carbon fixation, moisture level) unknowns that impact IPM programs. By quantifying hypothetical possibilities of how much money could be spent on monitoring and control activities before these expenditures exceed potential savings, unexpected outcomes can be avoided.

A number of standard economic techniques serve to reduce uncertainty. Some techniques are relatively simple and provide only gross predictions of possible results, but others are relatively complex and provide detailed statistical or mathematical information about models. Specifically, these include: 1) worst-/best-case scenario, 2) contrived scenarios, 3) decision tree analysis, 4) sensitivity analysis, 5) Monte Carlo simulation, and 6) systematic projections.

Worst-/best-case scenario calculations are the simplest approach to uncertainty reduction. The farmer, extension agent, or researcher quantifies the assumed most costly and least costly monitoring and control scheme that s/he thinks will occur for the crop cycle or year. The worst-case scenario is determined using the assumed most frequent and most expensive pest-monitoring procedure(s) and the most frequent and most expensive pest-control application(s), coupled with the assumed smallest potential yield and greatest possible damage, to compute the lowest expected harvest and IPM output. The best-case scenario is projected using the assumed least frequent and least expensive pest-monitoring procedure(s) and the least frequent and least expensive pest-control application (s), coupled with the assumed greatest yield and least damage, to compute the highest expected harvest and IPM value. While only bracketing the lowest and highest potential returns on investments, these two scenarios at least provide rough lower and upper bounds for assessing the IPM program.

Contrived (multiple) scenarios are simply an expansion of the worst-/best-case example. These scenarios refer to a logical set of hypothetical events that the farmer, extension agent, or researcher believes will occur in the agro-ecosystem during the crop cycle or year. Multiple scenarios of interest are generated and quantified. For example, a "mixed" scenario might be included with the worst-/best-case example above to examine costs and savings associated with the assumed most frequent and most expensive pest-monitoring procedure(s) but include a single least expensive pest-control application, coupled with the assumed smallest yield and greatest pest damage, to compute an expected harvest and IPM estimate. Other sophisticated scenarios could be com-

puted to derive the expected costs and potential savings based on a set of well-expressed assumptions. This approach further reduces uncertainty by providing likely IPM outcomes for a set of possible costs and savings contingencies affecting the IPM program.

Decision tree analysis examines sequential probabilities of specified IPM schemes to reduce the uncertainty over multiple seasons or years (Zerbe and Dively 1994, Shwiff and Sterner 2002). Essentially, it is a form of scenario-based analysis that uses a graphic illustration of branched probabilities to show the expected outcomes and contingencies. Suppose that IPM scenarios involved 4 potential approaches proposed by a farmer, extension agent, or researcher to allocate funds to undertake a 2-year IPM program. In Year 1, IPM-I might involve full funding for unlimited pest-monitoring and pest-control applications, IPM-II might involve a cut of 25% in this funding, IPM-III might involve a 50% cut in this funding, and IPM-IV might involve the complete elimination of funding. Year-2 scenarios would show how crop damage might change as monies are diverted away from (or allocated to) conducting IPM. Similarly, specific branches of the tree might entail an assumed 0% (no change), 10%, and 20% increase in pest damage over the time course of the scenarios.

Sensitivity analysis is used to assess how changes in a quantified variable reduce or limit the uncertainty of outcomes (Zerbe and Dively 1994, Shwiff and Sterner 2002). This is the technique most often used by economists to deal with uncertainty. The typical procedure entails regression analysis, which involves a linear regression equation to predict a dependent variable (IPM costs) using a set of possible pest-monitoring, pest-control, and crop-damage variables. For example, consider the following hypothetical regression equation of IPM effectiveness:

$$IPM = \beta 0 + \beta 1 x_i + \beta 2 y_i + \beta 3 z_i + e$$

where $\beta 0$ is the y-intercept, $\beta 1$ is a coefficient for pest-monitoring cost (x_i), $\beta 2$ is a coefficient for pest-control cost (y_i), $\beta 3$ is a coefficient for pest damage (z_i), and e is an estimate of residual error. By re-computing the equation using arbitrary values for $\beta 2$ (e.g., decreased 25% and increased 25%), the farmer, extension agent, or researcher can examine how "sensitive" the IPM variable is to changes in pest-control expenses. Again, depending on the changes in the equation after these re-computations with arbitrary coefficients, uncertainty about the IPM variable due to altered control inputs will be lessened.

Monte Carlo simulation refers to a computer-based, probabilistic-modeling procedure that usually requires empirical estimates of likely reductions in damage attributable to pest-monitoring or -control activities (Peterson and Hunt 2003, Zerbe and Dively 1994). A sampling distribution of probable variations in damage is generated and then sampled to project the likely outcomes for IPM-related damages using selected combinations of the monitoring and control probabilities. Suppose experience has shown that 3, 4, and 5 pest-monitoring events are associated with a 30%, 50% and 30% reduction in damage (i.e., 4 monitoring events have afforded a greater probability of less damage than fewer or greater monitoring events). A computer model would

be prepared to link potential savings (or damages) to the sampling distribution for each of the outcomes, and the program would be run hundreds or thousands of times to examine likelihoods of probable returns on investment for each monitoring and probability combination.

Finally, systematic projections can be used, *a priori*, to estimate IPM costs and savings outcomes for all combinations of IPM costs and savings variables. Modern computer spreadsheet programs (e.g., Microsoft Excel) allow farmers, extension agents, and researchers to rapidly compute crop harvest outputs for hundreds of combinations of pest-monitoring, pest control, and likely crop loss inputs in seconds (Sterner 2002, 2008). Systematic insertion of specific values for crop, field size, pest damage, and IPM labor and material charge variables into economic models (e.g., Eq. 1 - 6 above) can be programmed using spreadsheet code. Iterative "runs" of the spreadsheet can then provide comprehensive estimates of costs and savings for extensive, diverse pest-crop scenarios using combinations of variables for model parameters. These projections can reduce the uncertainty about pest-surveillance and -control decisions.

DISCUSSION

A prime example of the use of IPM with rodents occurred in Australia (Ramsey and Wilson 2000). It involved the well-known mouse "plagues" that affected the southeastern grain-belt region of that country during the 1990s (Redhead et al. 1985, Redhead 1988). Three species of rodents were considered pests in this situation: 1) the cane field rat (*Rattus sordidus*) in sugarcane, 2) the roof rat (*R. rattus*) in macadamia nut orchards, and 3) the house mouse (*Mus musculus*) in cereal and oilseed crops (Ramsey and Wilson 2000). Estimates of crop-caused damage equates to ≈$A10 million (2007 Australian dollars) in the absence of IPM for these outbreaks (Ramsey and Wilson 2000). Rodent population monitoring showed that a 4-phase cycle characterized the shifts in rat and mouse numbers: 1) post-winter breeding and crop growth, 2) spring-to-summer population build-ups and crop maturation, 3) post-summer rodent die-off and plant harvest, and 4) over-winter low population density and crop/habitat dormancy. Using a multi-simulation approach, successive intervention points of rodent control (bait application) before, at, or after recognition (anticipation) of a given pest population size (D), with an assumed population reduction of ≥80%, was shown to yield less total damage and increased crop savings (Ramsey and Wilson 2000). While the hypothetical study did not afford direct estimates of IPM- and rodenticide-bait-induced savings, it was concluded that persistent surveillance and timed-bait applications would yield control of rodent populations and decreased plague impacts.

The list of U.S. agricultural crops and activities include more than 150 specific farming activities, crops, and commodities, e.g., 7 dry bean/pea, 35 field, 29 fruit, 6 nut, 13 specialty, 30 vegetable, and >25 activities (see NASS 2007). Obviously, not all of these crops or species/groups of vertebrate pests warrant IPM programs– the benefits-costs of such long-term monitoring and control activities may be unwarranted, based

upon local or regional economics. Populations of selected rodent and bird species meet fecundity and density criteria most analogous to insects (Ramsey and Wilson 2000, Linz 2003). Still, IPM has been used with certain North American carnivore populations (e.g., coyotes, foxes) for livestock protection (U.S. GAO 1990, USDA 1994, Bodenchuk et al. 2002).

In conclusion, as early as the 1980s, biologists both recognized the utility of IPM schemes for vertebrates and cautioned against establishing rigid ETs and EILs for these species (Marsh 1981). IPM economic principles devised by entomologists have been shown applicable to grain crops and rodent damage (Ramsey and Wilson 2000). Uncertainty reduction techniques can aid IPM decision-making in these situations (see Sterner 2002, 2008).

ACKNOWLEDGMENTS AND DISCLAIMER

LITERATURE CITED

ALLEN, G. E., and J. E. BATH. 1980. The conceptual and institutional aspects of integrated pest management. BioScience 30:658-664.

ALSTON, D. G. 1996. Pest management decision-making: The economic-injury level concept. Web site. Utah State University Extension Electronic Publishing. Available at: http://extension.usu.edu/htm/publications/by=author/char=A/author=82/start=21. Accessed April 10, 2008. 3 pp.

ANDERSON, D. R. 2001. The need to get the basics right in wildlife field studies. Wildl. Soc. Bull. 29:1294-1297.

BODENCHUK, M. J., J. R. MASON, and W. C. PITT. 2002. Economics of predation management in relation to agriculture, wildlife, and human health and safety. Pp. 80-90 in: L. Clark, J. Hone, J. A. Shivik, R. A. Watkins, K. C. VerCauteren, and J. K. Yoder (Eds.), Human Conflicts with Wildlife: Economic Considerations. USDA APHIS, Wildlife Services, National Wildlife Research Center, Fort Collins, CO.

CARLSON, R. 1962. Silent Spring. Houghton Mifflin, New York. 355 pp.

CATE, J. R., and M. K. HINKLE. 1994. Integrated pest management: The path of a paradigm. National Audubon Society, Washington, D.C. 40 pp.

COUNCIL ON ENVIRONMENTAL QUALITY. 1972. Integrated pest management. U.S. Government Printing Office, Washington, D.C. 42 pp.

DEANGELIS, M. L., D. A. HANAN, and B. E. CURRY. 2008. Preliminary observations of the effectiveness of non-lethal deterrence methods for California sea lions and pacific harbor seals along the coast of California. Proc. Vertebr. Pest Conf. 23:181-185.

DUFFY, M. D. 1997. Alternative approaches to decision making. Pp. 74-85 in: L. G. Higley and L. P. Pedigo (Eds.), Economic Thresholds for Integrated Pest Management. University of Nebraska Press, Lincoln, NE.

ENGEMAN, R. M. 2003. More on the need to get the basics right: population indices. Wildl. Soc. Bull. 31:286-287.

FITZNER, M. S. 2002. Three decades of federal integrated pest management policy. Pp. 1-24 in: W. B. Wheeler (Ed.), Pesticides in Agriculture the Environment. CRC Press, Boca Raton, FL. 360 pp.

FLETCHER, B. 2008. Exploding populations of California sea lions: A crisis with no political solution on the horizon. Proc. Vertebr. Pest Conf. 23:178-180.

HIGLEY, L. G., and L. P. PEDIGO (EDITORS). 1997. Economic Thresholds for Integrated Pest Management. University of Nebraska Press, Lincoln, NE. 327 pp.

HYGNSTROM, S. E., R. M. TIMM, and G. E. LARSON (EDITORS). 1994. Prevention and Control of Wildlife Damage. Nebraska Cooperative Extension Service, Lincoln, NE. 848 pp.

IUCN (INTERNATIONAL UNION FOR THE CONSERVATION OF NATURE AND NATURAL RESOURCES). 2007. Web site. The IUCN Red List of Threatened Species™ Summary Statistics. Available at: http://www.iucnredlist.org/infocategories_criteria1994 and http://www.iucnredlist.org/info/tables. Accessed October 31, 2007.

KOGAN, M. 1986. Ecology Theory and Integrated Pest Management. John Wiley and Sons, New York. 362 pp.

KOGAN, M. 1998. Integrated pest management: Historical perspectives and contemporary developments. Ann. Rev. Entomol. 43:243-270.

LINZ, G. M. (EDITOR). 2003. Management of North American blackbirds. Proceedings of a Special Symposium, 9th Annual Conference of The Wildlife Society, Bismarck, ND. USDA National Wildlife Research Center, Fort Collins, CO. 118 pp.

MARSH, R. E. 1981. The unrealistic IPM parameters of vertebrate pest control. Proc. Gt. Plains Wildl. Damage Control Wkshp. 5:109-110.

(NASS) NATIONAL AGRICULTURE STATISTICAL SERVICE. 2007. Agricultural Prices. http://www.nass.usda.gov. Accessed July 20, 2007.

NATIONAL RESEARCH COUNCIL. 1996. Ecologically Based Pest Management: New Solutions for a New Century. National Academy Press, Washington, D.C. 124 pp.

PEDIGO, L. R., and L. G. HIGLEY. 1997. Introduction to pest management thresholds. Pp. 3-8 in: L. G. Higley and L. R. Pedigo (Eds.), Economic Thresholds for Integrated Pest Management. University of Nebraska Press, Lincoln, NE.

PETERSON, R. K. D., and T. E. HUNT. 2003. The probabilistic economic injury level: Incorporating uncertainty into pest management decision-making. J. Econ. Entomol. 96:536-542.

RAMSEY, D. S. L., and J. C. WILSON. 2000. Towards ecologically based baiting strategies for rodents in agricultural systems. Int. Biodeter. Biodegrad. 45:183-197.

REDHEAD, T. D. 1988. Prevention of plagues of house mice in rural Australia. Pp.191-205 in: I. Prakash (Ed.), Rodent Pest Management. CRC Press, Boca Raton, FL.

REDHEAD, T. D., N. ENRIGHT, and A. E. NEWSOME. 1985. Causes and predictions of outbreaks of *Mus musculus* in irrigated and non-irrigated cereal farms. Acta Zoologica Fennica 173:125-127.

SHWIFF, S. A., and R. T. STERNER. 2002. An economic framework for benefit-cost analysis in wildlife damage studies. Proc. Vertebr. Pest Conf. 20:340-344.

SMITH, R. F. R., and R. VAN DEN BOSCH. 1967. Integrated control. Pp. 295-340 in: W. W. Kilgore and R. L. Doutt (Eds.), Pest Control: Biological, Physical, and Selected Chemical Methods. Academic Press, New York. 477 pp.

STERN, V. M. 1973. Economic thresholds. Ann. Rev. Entomol. 18:259-280.

STERN, V. M., R. F. SMITH, R. VAN DEN BOSCH, and K. S. HAGAN. 1959. The integration of chemical and biological control of the spotted alfalfa aphid. Part I. The integrated control concept. Hilgardia 29:81-101.

STERNER, R. T. 2002. Spreadsheets, response surfaces and intervention decisions in wildlife damage management. Pp. 42-47 *in*: L. Clark, J. Hone, J. A. Shivik, R. A. Watkins, K. C. VerCauteren, and J. K. Yoder (Eds.), Human Conflicts with Wildlife: Economic Considerations. USDA APHIS, Wildlife Services, National Wildlife Research Center, Fort Collins, CO.

STERNER, R. T. 2008. Reducing the uncertainty of IPM economics. Pp. 163-180 *in*: E. N. Burton and P. V. Williams (Eds.), Crop Protection Research Advances. Nova Science Publishers, Inc., Hauppauge, NY.

STERNER, R. T., D. J. ELIAS, M. V. GARRISON, B. E. JOHNS, and S. R. KILBURN. 1984. Birds and airport agriculture in the conterminous United States: A review of literature. Pp. 319-329 *in*: M. J. Harrison, S. A. Gauthreaux, Jr., and L. A. Abron-Robinson (Eds.), Proc. Wildlife Hazards to Aircraft Conference, (DOT/FAA/AAS/84-1), U.S. Dept. of Transportation, Washington, D.C.

USDA (U.S. DEPARTMENT OF AGRICULTURE). 1994. Animal Damage Control Program: Final Environmental Impact Statement. U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control Program, Washington, D.C. Vols. 1, 2, and 3.

U.S. GAO (U.S. GENERAL ACCOUNTING OFFICE). 1990. Wildlife management: Effects of animal damage control program on predators. Report to the Hon. Alan Cranston (August 1990), GAO/RCED-90-149, U.S. General Accounting Office, Washington, D.C. 31 pp.

U.S. GAO (U.S. GENERAL ACCOUNTING OFFICE). 2001. Agricultural pesticides: Management improvements needed to further promote integrated pest management. Report to the Chairman, Subcommittee on Research, Nutrition, and General Legislation, Committee on Agriculture, Nutrition, and Forestry, U.S. Senate, GAO-01-815, U.S. General Accounting Office, Washington, D.C. 33 pp.

WHITE, G. C., D. R. ANDERSON, K. P. BURNHAM, and D. L. OTIS. 1982. Capture-recapture and removal methods for sampling closed populations. U.S. Department of Energy, Los Alamos National Laboratory, Research Publication LA-8787-NERP, Los Alamos, NM. 235 pp.

WHITE, G. C., and B. C. LUBOW. 2002. Fitting population models to multiple sources of observed data. J. Wildl. Manage. 66:300-309.

WITMER, G. 2007. The ecology of vertebrate pest management and integrated pest management (IPM). Pp. 393-410 *in*: M. Kogan and P. Jepson (Eds.), Perspectives in Ecological Theory and Integrated Pest Management. Cambridge University Press, Cambridge, UK. 588 pp.

ZERBE, R. O., and D. D. DIVELY. 1994. Benefit-cost Analysis in Theory and Practice. HarperCollins College Publishers, New York. 557 pp.