Chapter 24
On Estimating the Economic Value of Insectivorous Bats: Prospects and Priorities for Biologists

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Abstract Bats are among the most economically important nondomesticated mammals in the world. They are well-known pollinators and seed dispersers, but crop pest suppression is probably the most valuable ecosystem service provided by bats. Scientific literature and popular media often include reports of crop pests in the diet of bats and anecdotal or extrapolated estimates of how many insects are eaten by bats. However, quantitative estimates of the ecosystem services provided by bats in agricultural systems are rare, and the few estimates that are available are limited to a single cotton-dominated system in Texas. Despite the tremendous value for conservation and economic security of such information, surprisingly few scientific efforts have been dedicated to quantifying the economic value of bats. Here, we outline the types of information needed to better quantify the value of bats in agricultural ecosystems. Because of the complexity of the ecosystems involved, creative experimental design and innovative new methods will help advance our knowledge in this area. Experiments involving bats in agricultural systems may be needed sooner than later, before population declines associated with white-nose syndrome and wind turbines potentially render them impossible.

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24.1 Introduction

Bats play many vital roles in ecosystems worldwide as pollinators, major predators of arthropods, and seed dispersers (Kunz et al. 2011). These "ecosystem services" are hugely beneficial to humans, and bats are likely one of the most economically important nondomesticated groups of mammals (Boyles et al. 2011; Kunz et al. 2011). Still, public perceptions of bats are often negative, and this discordance between perception and reality may make bats among the most undervalued of all vertebrate groups. Arguments about the value of bats have historically been limited to anecdotal accounts of how many insects a single bat can consume or the crops that rely on bats for seed dispersal or pollination. Although these arguments are helpful in changing perceptions about bats, they often fail to establish the relevance of bats to the public, a problem which may be solvable by placing the value of bats in a context that is widely appreciated—money. There have been several recent attempts to place monetary values on the pest control services provided by bats, and resulting estimates are impressively large (Boyles et al. 2011; Cleveland et al. 2006; Federico et al. 2008b). Although these estimates have gained traction in the public media and as effective arguments for bat conservation, our scientific understanding of ecosystem services provided by bats is so underdeveloped that all estimates to date have been quite imprecise. Unfortunately, even such imperfect estimates are unavailable for the economic value of bats as seed dispersers and, except for Bumrungsri et al. (2009), as pollinators. These deficiencies in our ability to accurately quantify the value of bats only hinder public appreciation and efforts to justify conservation efforts directed toward this misunderstood group of mammals.

Our goal in this chapter is to provide recommendations on where researchers might focus their efforts in the next decade to more thoroughly describe the economic value of bats. Kunz et al. (2011) have provided a prospectus on the economic methodologies available to estimate the value of those services; therefore, we will expand the discussion with research recommendations regarding the largest functional group of bats, the insectivores (Kunz et al. 2011), and what we need to know to quantify their economic importance.

24.2 The Science of Value Estimation: Insectivorous Bats as Pest Controllers

In general, we see two promising scientific approaches to estimate the value of bats in controlling crop pests. First, we can attempt to study, understand, and parameterize each component of a model describing the value of bats, including the population size of bats in an area, what prey species those bats eat, how many insects of each species they eat, and the effects of bat predation on the insect populations. Second, we can take a more holistic approach and attempt to understand the effects of bats on crop production without attempting to understand the underlying processes. Each approach has advantages. The first approach will greatly increase our understanding of basic bat biology, allow for evaluation of how each factor affects the overall value of bats, and is likely to have greater heuristic value for attempting to evaluate other crop/insect/bat food webs worldwide. However, getting at those underlying processes will be time consuming, logistically difficult, and in some cases (e.g., species of bats that cannot be counted) impractical. The second approach of tracking bat-associated changes in crop production may lead to quicker and more direct answers but, because the underlying processes are ignored, will likely provide less insight into other systems worldwide. We will address each of these approaches in turn, beginning with the individual processes we need to understand to describe the whole system.

24.2.1 What Bats Eat

Given the long history of studies on diets of insectivorous bats (e.g., Agosta 2002; Brack and LaVal 2006; Clare et al. 2011; Kurta and Whitaker 1998; Tuttle et al. 2006; Whitaker 1995, 2004; Whitaker and Clem 1992; Whitaker and Rissler 1993; Whitaker et al. 1997), it may seem odd that we believe one of the most important research areas as we move forward is determining what bats eat. Traditional diet analyses, based on visually identifying insect fragments in bats' feces to the lowest taxonomic level possible and largely pioneered by Dr. John Whitaker, Jr. (Whitaker 1988), provide an incredible amount of information about what insects some bat species consume. However, these traditional analytical techniques have limitations, such as biases caused by differences in digestibility among prey, limited ability to detect very small prey, and difficulty in identifying remains below the ordinal level (Whitaker et al. 2009). Traditional diet analyses are also very time consuming, so mass sampling of bat diets, and thus continent- or global-scale evaluation of bat diets, is unlikely.

Molecular techniques, which are rapidly developing, clearly offer a promising research pathway. A huge number of insect species in the diets of certain bats have been identified using PCR amplification and bar coding sequence analysis of DNA extracted from insect fragments in bat feces (Clare et al. 2009, 2011). Still, these techniques require the separation of fecal material, so digestibility issues might hinder the identification of small or soft prey using this approach. Further, the time involved with mechanical separation of feces means that analyses of bat diets on large geographic scales are limited by sample processing time. In most instances, different genetic markers are needed to identify different insect groups. This not only increases analytical costs exponentially but also limits prey identification to the selected target group and requires a priori knowledge of prey species (King et al. 2008). Whole fecal sample extraction followed by PCR and molecular cloning for DNA bar codes of targeted taxa (Zeale et al. 2011) has recently provided a more efficient approach for identification of phylogenetically diverse insects in the diet of bats, but as in all bar code studies, a reference database of sequences from known available insects is required. Another limitation of this technique is the cost associated with using large numbers of clones per sample, which in turn may result in the failure to detect less abundant prey items (Alberdi et al. 2012). The use of next-generation sequencing techniques allows even more efficient analysis of dietary diversity and resource partitioning in insectivorous bats where reference sequence data are lacking for available insect prey. Two recent studies using Roche FLX 454 high-throughput DNA sequencing techniques allowed PCR of fecal samples from multiple bats using uniquely tagged insect-generic primers in which prey items were identified as molecular operational taxonomic units (MOTU's) (Razgour et al. 2011; Bohmann et al. 2011). In both studies, greater taxonomic precision was obtained by combining the molecular data with traditional identification of insect fragments and additional references to known sequences in DNA bar code databases (e.g., Lepidoptera Barcode of Life; http://www.lepbarcoding.org/). As reference bar code data expand, these techniques will allow increasing specificity in identifying the insect prey of bats. Future advances in sequence technology will only increase our ability to analyze a large number of samples at even lower costs (Pompanon et al. 2012).

As suggested by Whitaker (1988), traditional diet analyses based on identifying insect fragments in bats' feces provide two types of information: "percent frequency" (i.e., the proportion of fecal samples or fecal pellets containing a given prey item) and "percent volume" (i.e., the proportion of the fecal sample comprised of specific prey item or taxon). Although molecular techniques are much refined in identifying dietary diversity in bats, most published molecular assays to date provide information only on "percent frequency" (see Table 2 in Razgour et al. 2011). A major limitation in our current understanding of bat diets, especially for assessing possible impacts on insect populations, is quantifying the amount of each prey type being consumed by bats. To this end, the use of quantitative PCR (qPCR) has been used to estimate numbers of gene copies of sequences from targeted insect species in fecal samples from individual bats (McCracken et al. 2012). Calibrated as numbers of gene copies per mass unit of feces, this approach could provide information analogous to "percent volume" of a prey item. Although captive feeding studies to calibrate this approach indicate that there are many complications in relating gene copy numbers from qPCR to estimates of biomass or numbers of prey consumed (McCracken et al. 2012), with proper controls such an analysis may be feasible. The rapid development of deep-sequencing and high-throughput technologies also suggests that targeted prey soon will be quantifiable using tagged insect-specific primers.

24.2.2 The Energetics of Insectivorous Bats

The study of energetics provides another link connecting what a bat species eats to how many insects are eaten. The modern study of energetics in bats goes back to at least the 1940s (e.g., Hock 1951; Pearson 1947), and interest in the topic goes back considerably further (Hall 1832). Until recently, the vast majority of studies on the energetics of bats have relied on metabolic measurements done in artificial chambers (e.g., Dunbar and Tomasi 2006; Hock 1951; Kelm and von Helversen 2007; Thomas et al. 1990; Willis et al. 2005), which are difficult to extrapolate to free-living bats. More importantly, estimates of the cost of flight in insectivorous bats (e.g., Speakman and Racey 1991) are surprisingly rare and are likely to vary among species because of differences in morphology (Norberg and Rayner 1987), so fully parameterizing models estimating energy expenditure is presently difficult. However, several analytical techniques are becoming more readily available and cheaper and are therefore quickly increasing in use. For example, the doubly labeled water technique is gaining popularity as a way of estimating energy expenditure in free-ranging bats (Kurta et al. 1989; Voigt and Lewanzik 2011; Voigt et al. 2006), and heart rate monitors, commonly used to estimate the cost of flight in free-ranging birds (e.g., Sapir et al. 2010), are being applied to bats as well (Dechmann et al. 2011; Studier and Howell 1969). The data from such empirical studies can then be used to model the energetics of bats under natural, and varying, conditions (Boyles and Brack 2009; Boyles and McKechnie 2010; Boyles and Willis 2010; Federico et al. 2008a). With additional refinement, long-term, holistic estimates of energy expenditure in free-living bats may be possible. These types of studies will be vital in estimating the energy expenditure, and therefore the energy (and biomass) intake, of insectivorous bats.

Describing the energetic expenditure of free-ranging bats will be most useful in this context if those data are supplemented with information about the energy and mineral content available in individual prey insects (Encarnação and Dietz 2006). A few studies estimating the energetic and mineral content of insect prey were done decades ago (Keeler and Studier 1992; O’Farrell et al. 1971; Studier and Sevick 1992), but such studies are rare of late. Combining dietary composition estimates derived using molecular techniques with the energetic intake of free-ranging bats and the energetic content of prey should allow for more thorough and accurate estimates of species-specific biomass intake than have been possible in the past (e.g., Anthony and Kunz 1977).

24.2.3 Estimating Bat Populations

One of the major limiting factors in fully understanding the value of bats to agriculture is quantifying the number of bats in a region. Previous authors have noted both the difficulties in estimating bat populations and the outlook for future techniques that might be useful (O’Shea and Bogan 2003). Recent work has highlighted the problems with some historical population estimates (Betke et al. 2008; Meretsky et al. 2010), and new and creative ways of better estimating population sizes or trends are needed. The need for better monitoring methods is especially pressing in light of the massive population crashes associated with white-nose syndrome (Blehert et al. 2009; Frick et al. 2010; Turner et al. 2011) and the high levels of bat mortality observed at wind power facilities (Cryan and Barclay 2009; Kunz et al. 2007).

The ability to obtain genetic data on bats noninvasively from their fecal samples (Puechmaille and Petit 2007; Vege and McCracken 2001), coupled with statistical analyses based on observed genetic diversity, provides an opportunity to estimate population sizes (Leberg 2005; Luikart et al. 2010). A straightforward approach involves estimating the numbers of individuals in a specified area with data from multiple polymorphic microsatellite loci in which an individual is recognized based on its genetic fingerprint. By relating the number of distinct genotypes to the number of samples and using the asymptote of the curve, minimum population size can be estimated (Creel et al. 2003; Leberg 2005; Luikart et al. 2010). Puechmaille and Petit (2007) successfully applied this technique to estimate the numbers of bats in a colony while also providing perspective on the potential pitfalls and limitations of such analyses. Because bats are highly vagile and some species frequently move between numerous roost sites, estimates of the number of bats in a colony may have little to do with the actual numbers of bats on the landscape that are contributing to pest suppression. Nonetheless, it is easy to envision a situation where estimating the quantity of insects eaten by a given colony of bats could be a compelling message for bat conservation. Other approaches based on likelihood and coalescent methods have been developed and applied (Leberg 2005; Luikart et al. 2010) to provide estimates of effective population sizes (Russell et al. 2011). While these approaches have the potential for estimating total numbers of individuals of a given species on the landscape, there are significant limitations and caveats. First, effective population size differs and is typically some fraction of total population or census size (Leberg 2005; Luikart et al. 2010), and the conversion of census size to effective size depends on a suite of demographic and behavioral characteristics that differ among bat populations and species and are probably poorly known. Second, likelihood and coalescence methods provide historical signatures to population sizes and changes in population size. The molecules employed and their rate(s) of evolution determine the historical “depth” of the estimates obtained, and these estimates may have little to do with the sizes of populations that are presently on the landscape (Russell et al. 2011). Lastly, these estimates typically have confidence limits that span orders of magnitude (Luikart et al. 2010; Russell et al. 2011). In sum, a number of concerns exist around noninvasive genetic sampling techniques and population size estimation (Luikart et al. 2010; Pompanon et al. 2005; Waits and Paetkau 2005); however, as both the molecular techniques and models improve, these limitations will likely become less restrictive.

Bats themselves can add to the complexity of investigating their diet, their population size, and their energetic needs because species of economic importance could possibly be part of a larger species complex. In such cases, it would be easy to imagine a situation where morphologically similar species exhibit behavioral and/or ecological differentiation. This differentiation will be important when studying the suppression of crop pests by specific bat species, so understanding this variation by exploring the genealogical relationships (Avise 2000) between cryptic bat species will be an added critical contribution to our understanding of diets, energetics, and population sizes of cryptic species and the differences between them. Future studies on the intra- and interspecific relationships of insectivorous bats will thus be important as we attempt to distinguish suppression of insects by species of conservation concern from suppression by the bat community as a whole.

24.2.4 The Effects of Bats on Insect Populations

Bats and their insect prey represent a textbook example of a coevolutionary arms race that has evolved over millions of years (Conner and Corcoran 2012). Although work describing predator/prey interactions of bats and insects at the level of individuals is common (e.g., Conner and Corcoran 2012; Corcoran et al. 2009; Pavey et al. 2006), few studies have evaluated the population, community, and ecosystem ramifications of such interactions on the insect prey. Bats face very large energetic demands because of flight and must consume huge amounts of insect biomass each night (Kurta et al. 1989). This fact, coupled with historically large bat populations, leads to the understandable assumption by some that the collective impacts of bat communities on insect populations and community structure may therefore be substantial (Whitaker 1995; Whitaker and Clem 1992). However, there are reasons to believe that bats may not actually suppress insect populations. For example, many bats have broad diets suggesting they forage opportunistically on available prey and may therefore best be classified as "generalist predators" (Clare et al. 2009). As such, it may be that many insectivorous bats, as has been suggested for other generalist predators, do not exert sufficient predation pressure on any one insect species to substantially affect its population dynamics (Knipling 1979). Although this idea has gained traction in the biocontrol literature, an opposing school of thought suggests that generalist predators of insects can suppress prey populations if they can (1) persist on alternative prey when populations of any one insect species decline and (2) rapidly exploit populations of insects as those populations increase (Symondson et al. 2002). The longevity of bats (Wilkinson and South 2002) suggests they must be able to survive as insect populations wax and wane, and many studies have reported that bats often take advantage of transient insect populations (Belwood and Fenton 1976; Fenton and Morris 1976; Storm and Whitaker 2008). In fact, theoretical and empirical work suggests that other generalist predators can suppress insect populations (Riechert and Lockley 1984); therefore, bats deserve study in this area.

It is clear that bats eat substantial numbers of insects (Cleveland et al. 2006; Whitaker 1995), yet surprisingly few if any studies have directly quantified how bat predation affects crop pest populations in natural settings. Simply noting a prey species in the diet of a bat is not sufficient evidence that bats act as biological control agents on that specific pest. Most importantly, the short generation times and high reproductive rates of many insects suggest that adult survival may actually play only a small role in overall population growth. A good example of this disparity in life history characteristics between predator and prey involves predation of Brazilian free-tailed (*Tadarida brasiliensis*) bats on adult cotton bollworm moths *Helicoverpa zea* (Lepidoptera: Noctuidae). Importantly, it is the larval stage of corn earworms that damage crops and wildflowers (Cleveland et al. 2006), and even with predation of adult *H. zea* by bats, far more moth eggs are laid on each plant than can survive. In fact, mortality at the egg stage may account for the major limiting factor in population growth of cotton bollworms in some years (Sansone and Smith 2001). Still, predation by Brazilian free-tailed bats does appear to lessen the number of eggs that actually make it onto plants, which likely slows population growth rate enough to delay much of the damage to harvested crops (Cleveland et al. 2006). This predation on adult *H. zea* is especially important in years when the natural predators on *H. zea* eggs (mostly pirate bugs; *Orius* spp.) are rare.

Estimating the impacts of bat predation on insect populations may be further complicated by both spatial and temporal environmental variation leading to variation in population dynamics of the pest. For example, some pest species may be univoltine (one brood per year) at northern latitudes, but could have multiple broods per year at southern latitudes because of increases in temperature-dependent development rates and longer summers (Nielsen et al. 2008). Likewise, insect egg laying can occur at different times, even in agroecosystems located in close proximity (Sansone and Smith 2001) due to local differences in growing regimes (e.g. planting dates, crop varieties, irrigation, fertilization). Thus, not all predation by bats on crop pests is equal if bats are not eating the pest during the life stage that does damage to crops. For example, predation on adult moths late in the growing season is unlikely to have a strong effect on insect populations if the insects have already laid most or all of their eggs. Thus, estimates of the number of insect eggs that bat predation removes from an agroecosystem (Whitaker 1995) may be oversimplified if the temporal importance of predation events is not carefully considered.

Quantifying the effect of predation by bats (or any biocontrol agent) on a population of insects requires additional experimentation or a thorough understanding of the life history and demography of the pest in question (Stark and Banks 2003). Experimental assessments of the impacts of bats on pest populations may be possible with enclosures, but care must be taken in interpreting such results. For example, northern bats (*Myotis septentrionalis*) suppress mosquito populations in enclosures (Reiskind and Wund 2009), but there is little evidence that northern bats consume mosquitos in natural settings, and even when they do, mosquitos make up only a small percentage of northern bats' diets (Whitaker 2004).

Clear and consistent terminology is an important component of any advancing field of research. Because bats are unlikely to eliminate a crop pest, we suggest the appropriate terminology is that bats may *suppress* insect populations, and not *control* them. Put differently, use of the word "control" intimates that a specific pest should not exist where there is bat predation, while "suppress" more accurately suggests that bats can affect a pest population. Our goal as researchers should be never to mislead the public about the value of bats but instead to set realistic estimates of their economic worth to humans.

24.2.5 Holistic Evaluations of Crop Damage Suppression by Bats

Given the pressing conservation concerns surrounding bats (i.e., white-nose syndrome and high mortality at wind power facilities) and the high likelihood of drastic populations changes in the next few years (Frick et al. 2010), less time consuming and logistically more practical alternative means of assessing pest suppression by bats are needed. Because of the rapidly developing impact of the white-nose syndrome (WNS) epizootic, bat populations have already crashed in the northeastern and mid-Atlantic regions of the USA and Canada, and populations in the Midwest may experience the same fate in the near future. Thus, WNS is acting as a natural, albeit unfortunate, experiment on a scale we could never replicate. Direct comparisons of crop damage before and after population crashes might provide clues to the overall value of bats in pest suppression, but there is a vital need for pre-WNS baseline data. By the time this book reaches publication, it may be too late to collect such data in bat communities of the eastern USA, but an opportunity will likely still exist to do this type of work in the Midwest and western USA.

The most efficient way to address the value of bats to agriculture may be through experimental exclusion of bats in areas with healthy bat populations. Such exclusions have been done in a few forest and agroforest ecosystems (Böhm et al. 2011; Kalka et al. 2008; Morrison and Lindell 2012; Williams-Guillen et al. 2008), but no comparable studies are available from agricultural areas. Exclusion studies in agricultural regions will require researchers to overcome several logistical challenges. First, predation by bats and birds must be separated, likely through the use of exclusions that can be opened and closed at sunrise and sunset (Morrison and Lindell 2012). Second, the exclosures will have to be large enough to eliminate both direct and indirect effects of predation; i.e., echolocation pulses emitted by bats outside of the exclosures must not elicit antipredator responses of insects inside the exclosure. Determining the correct size of enclosures will take some trial and error depending on the echolocation frequencies and intensities of the bats that are being excluded. Third, terrestrial dispersal of crop pests (especially in the larval stages) will have to be controlled so that pest densities within the exclosures are not affected by immigration of larval stage pests from outside. Finally, well-known effects of exclosures, like birds using the frame as a perch and thus increasing predation on insects in the area, will have to be addressed. However, these problems should all be solvable with innovative experimental design. Further, crops which are planted with wide spacing (e.g., fruit trees) may lend themselves to exclusion more readily than field crops like corn, soybeans, or cotton.

Indirect evidence may also provide clues into the overall value of bats in agroecosystems without necessarily leading to an understanding of the process underlying the system. For example, data on pesticides purchased and applied have been collected by the United States Department of Agriculture (USDA). An increase in pesticides purchased after WNS affects an area might provide inferential evidence that bats were important in pest suppression in the area, but such correlative evidence will obviously be confounded by a variety of factors. Regardless, a comparison between pesticide use and bat population declines should be feasible when the pesticide use data for the years since the beginning of the WNS epizootic become available.

24.2.6 Can the Value of Bats in Agriculture Be Increased?

While the dynamics of such complex predator/prey systems might seem beyond our influence, there may be several opportunities to impact the behavior of bats or the dynamics of bat predation on crop pests so as to increase the strength of top–down suppression of insects by bats in agroecosystems. The most obvious prospect is to increase the density of bat populations by providing artificial roosting structures to replace those lost during the conversion of natural habitat into agricultural landscapes (Flaquer et al. 2006). There is evidence that providing such artificial structures may attract bats to agricultural areas (Long et al. 2006), but to our knowledge, there is only anecdotal evidence that such structures increase foraging in the agroecosystems where the structures are placed (Kiser and Kiser 2002). We might also be able to influence the foraging behavior of bats by playing echolocation calls in agroecosystems. Many bat species are attracted by calls of conspecifics, especially calls associated with feeding ("feeding buzzes"; Gillam 2007). Thus, broadcasting recorded or simulated feeding buzzes may increase the density of foraging bats in agroecosystems, which should increase predation pressure on crop pests in the area. Such approaches also might be expected to alter the reproduction and population densities of crop pests, but the only study on the subject failed to find such effects (Gillam et al. 2011). Finally, alterations of the environment may change the dynamics of the predator/prey system. For example, it is well known that lights attract insects, and bats take advantage of the artificially increased insect densities (Rydell 1992). Further, lights also are known to hamper the ability of many moths to evade bat predation (Svensson and Rydell 1998), and recently, portable lights were shown to increase the prevalence of eared moths in the diets of bats after only a few days at a location (C. Minnaar, University of Pretoria, South Africa, *pers. comm.*). Many crop pests happen to be eared moths (e.g., *H. zea*), so lights placed in agroecosystems, even temporarily, might increase the predation rates of bats on crop pests and therefore lessen insect herbivory on crops. Undoubtedly, this is an area of research that deserves more attention in the future.

Increasing the foraging of bats over agricultural areas seems like a positive outcome, but we must also recognize that it may have negative effects on the bats. Specifically, foraging over crops may lead to increased exposure to pesticides (O'Shea and Clark 2002), which have wide-ranging impacts on the health and fitness of insectivorous species (O'Shea and Johnston 2009). Although generally phased out of widespread use in many countries, organochlorine pesticides (like DDT) that accumulate in the tissues of animals are still commonly used in some countries and are known to have detrimental effects on the health of bats and bat populations (Clark 1988). Newer pesticides that are more widely used are generally thought to be less detrimental to bats because they do not tend to accumulate in body tissues, although studies to confirm this assumption are lacking (O'Shea and Johnston 2009). Future studies of bats in agroecosystems may provide unique opportunities to develop a better understanding of the health effects of pesticides on insectivorous bats.

24.2.7 The Value of Bats in Developing Countries

The potential value of insectivorous bats in developing countries is often overlooked. Bats may be especially valuable in suppressing crop pests in areas dominated by sustenance agriculture, as well as playing important roles in suppressing arthropod disease vectors. In many parts of Africa, for example, sustenance farmers do not have access to modern pesticides, so it is reasonable to predict that bats may act as a primary suppressor of crop pests. In other areas, the pesticides available may be older, highly toxic chemicals, and thus, the loss of pest suppression by bats might lead to increased use of pesticides with substantial secondary effects. Thus, the relative value of bats may be greater in developing countries than in more developed regions, because even though the economic value of crops produced in developing countries is considerably less, their marginal value as food can be enormously greater (http://www.data.worldbank.org/indicator/NV.AGR.TOTL.ZS). Unfortunately, we know of no research estimating the impact of bats on crop pest populations in developing regions [but see Williams-Guillen et al. (2008) for an example in an agroforestry ecosystem in Mexico]. Because the public perception of bats in developing regions is often even worse than in developed countries, and because the greatest bat diversity occurs in developing regions, information on pest control services of bats in these areas may do more for bat conservation than many of the more direct programs already implemented.

24.3 Conclusions

The conservation of bats has taken on a newfound importance in light of WNS and high mortality at wind power facilities. Changing the public perception of bats is one of the most important ways that researchers can contribute to bat conservation efforts (Fenton 1997), and one of the easiest ways to change those perceptions is to attach tangible values to the ecosystem services provided by bats. Surprisingly, insect suppression by bats—one of their most obvious benefits to humans—is severely understudied (Boyles et al. 2011; Cleveland et al. 2006; Federico et al. 2008b). We do not wish to suggest that this research will be quick or easy, but it is important to the advancement of bat conservation.

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