



**A Study On Harmful Effects Of Invertebrate And Vertebrate Pests
And Their Biological Control In Indian Agriculture.**

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Abstract

Biological control is a method of restricting effects of harmful animals, pathogens and plants using other useful organisms, e.g. microorganisms, insects and plants that inhibit the harmful organisms. The method takes advantage of basic ecological interactions between organisms, such as predation, parasitism, pathogenicity and competition. Today, biological control is used primarily for controlling pests in crop cultivation. Advantages of biological control are that no artificial substances are added, and that pathogens / animals that develop resistance against biological control agents are rare. Biological control is an important component of integrated pest management. Biological control is the beneficial action of parasites, pathogens, and predators in managing pests and their damage. Biocontrol provided by these living organisms, collectively called "natural enemies," is especially important for reducing the numbers of pest insects and mites. Use of natural enemies for biological control of rangeland and wild land weeds (e.g., Klamath weed, St. Johnswort) is also effective. Plant pathogens, nematodes, and vertebrates also have many natural enemies, but this biological control is often harder to recognize, less well understood, and/or more difficult to manage. Conservation, augmentation, and classical biological control are tactics for harnessing natural enemies' benefits. Biocontrol (for vertebrates in particular, the manipulation of habitat conditions) should not be employed a priori, because, if done improperly, the treatment can create more problems than it cures. In fact, it can cause more problems than the use of poisons. With repeated poisoning of vertebrate pests there is concern about the possibility of subtle and undesirable physiological and behavioral responses, or of carcinogenic and mutagenic effects on both the target species and on non target populations. However, when a habitat is modified, there is little doubt but what it will produce more pronounced interactions with other species of animals than would usually result from population reductions caused by either chemosterilents or toxicants. Observations indicate that natural biomes have a well-established, stable, animal-soil-vegetation complex which usually is not delicately balanced. A natural change (e.g., by disease) or man-caused change (e.g., by shooting), in the density of a native species of browsing, grazing, seed-eating, or predatory mammal does not precipitate a dramatic "balance-of-nature" type chain reaction of responses by other components of the biological community.. There are two broad approaches to reducing the density of troublesome populations of rodents,

birds, predators, and other vertebrates. They are biological control and "conventional " methods of control. Control of vertebrates biologically implies the use of a biological process. This can be accomplished in several ways. One is by use of a biological agent such as a chemosterilant which disrupts successful breeding of the pest species; in another method a predator or disease may be used to increase the mortality rate.

Introduction

Biological control is a component of an integrated pest management strategy. It is defined as the reduction of pest populations by natural enemies and typically involves an active human role. Keep in mind that all insect species are also suppressed by naturally occurring organisms and environmental factors, with no human input. This is frequently referred to as natural control.. Natural enemies of insect pests, also known as biological control agents, include predators, parasitoids, and pathogens. Biological control of weeds includes insects and pathogens. Biological control agents of plant diseases are most often referred to as antagonists. Predators, such as lady beetles and lacewings, are mainly free-living species that consume a large number of prey during their lifetime. Parasitoids are species whose immature stage develops on or within a single insect host, ultimately killing the host. Many species of wasps and some flies are parasitoids. Pathogens are disease-causing organisms including bacteria, fungi, and viruses. They kill or debilitate their host and are relatively specific to certain insect groups. Each of these natural enemy groups is discussed in much greater detail in following sections. The behaviors and life cycles of natural enemies can be relatively

simple or extraordinarily complex, and not all natural enemies of insects are beneficial to crop production. For example, hyperparasitoids are parasitoids of other parasitoids. A successful natural enemy should have a high reproductive rate, good searching ability, host specificity, be adaptable to different environmental conditions, and be synchronized with its host (pest). A high reproductive rate is important so that populations of the natural enemy can rapidly increase when hosts are available. The natural enemy must be effective at searching for its host and it should be searching for only one or a few host species. Spiders, for example, feed on many different hosts including other natural enemies. It is also very important that the natural enemy occur at the same time as its host. For example, if the natural enemy is an egg parasitoid, it must be present when host eggs are available. No natural enemy has all these attributes, but those with several characteristics will be more important in helping maintain pest populations. There are three broad and somewhat overlapping types of biological control: conservation, classical biological control (introduction of natural enemies to a new locale), and augmentation.

Types Of Natural Enemies

Parasites, pathogens, and predators are the primary groups used in

biological control of insects and mites. Most parasites and pathogens, and many predators, are highly specialized and attack a limited number of closely related pest species.

Parasites

A parasite is an organism that lives and feeds in or on a host. Insect parasites can develop on the inside or outside of the host's body. Often only the immature stage of the parasite feeds on the host. However, adult females of certain parasites (such as many wasps that attack scales and whiteflies) feed on and kill their hosts, providing an easily overlooked but important source of biological control in addition to the host mortality caused by parasitism. Although the term "parasite" is used here, true parasites (e.g., fleas and ticks) do not typically kill their hosts. Species useful in biological control, and discussed here, kill their hosts; they are more precisely called "parasitoids."

Most parasitic insects are either flies (Order Diptera) or wasps (Order Hymenoptera). Parasitic wasps occur in over three dozen Hymenoptera families. For example, Aphidiinae (a subfamily of Braconidae) attack aphids. Trichogrammatidae parasitize insect eggs. Aphelinidae, Encyrtidae, Eulophidae, and Ichneumonidae are other groups that parasitize insect pests. It's important to note that these tiny to medium-sized wasps are incapable of stinging people. The most common parasitic flies are the typically hairy Tachinidae. Adult tachinids often resemble house flies. Their

larvae are maggots that feed inside the host.

Pathogens

Natural enemy pathogens are microorganisms including certain bacteria, fungi, nematodes, protozoa, and viruses that can infect and kill the host. Populations of some aphids, caterpillars, mites, and other invertebrates are sometimes drastically reduced by naturally occurring pathogens, usually under conditions such as prolonged high humidity or dense pest populations. In addition to a naturally occurring disease outbreak (epizootic), some beneficial pathogens are commercially available as biological or microbial pesticides. These include *Bacillus thuringiensis* or Bt, entomopathogenic nematodes, and granulosis viruses. Additionally, some microorganism by-products, such as avermectins and spinosyns are used in certain insecticides; but applying these products is not considered to be biological control.

Predators

Predators kill and feed on several to many individual prey during their lifetimes. Many species of amphibians, birds, mammals, and reptiles prey extensively on insects. Predatory beetles, flies, lacewings, true bugs (Order Hemiptera), and wasps feed on various pest insects or mites. Most spiders feed entirely on insects. Predatory mites that feed primarily on pest spider mites include *Amblyseius* spp., *Neoseiulus* spp., and the western predatory mite, *Galendromus occidentalis*.

Table 1. Some Pests and Their Common Natural Enemies.

	NATURAL ENEMIES					
PESTS	Lacewing s	Lady beetle s	Parasiti c flies	Parasiti c wasps	Pre dato ry mite s	Other Groups and Examples
aphids	X	X		X		entomopathogenic fungi, soldier beetles, syrphid fly larvae
carpenterwor m, clearwing moth larvae				X		entomopathogenic nematodes
caterpillars (e.g., California oakworm)	X		X	X		<i>Bacillus thuringiensis</i> , birds, entomopathogenic fungi and viruses, predaceous bugs and wasps, <i>Trichogramma</i> spp. (egg parasitic wasps), spiders
cottony cushion scale		X	X			<i>Cryptochaetum iceryae</i> (parasitic fly), vedalia beetle
elm leaf beetle			X	X		<i>Erynniopsis antennata</i> (parasitic fly), <i>Oomyzus (=Tetrastichus)</i> spp. (parasitic wasps)
eucalyptus longhorned borers				X		<i>Avetianella longoi</i> (egg parasitic wasp)
eucalyptus redgum lerp psyllid				X		<i>Psyllaephagus bliteus</i> (parasitic wasp)
giant whitefly	X	X		X		<i>Encarsia hispida</i> , <i>Encarsia noyesi</i> , <i>Entedononecremnus krauteri</i> , and <i>Idioporus affinis</i> (parasitic wasp), syrphid fly larvae
glassy-winged sharpshooter	X			X		assassin bugs, <i>Gonatocerus</i> spp. (egg parasitic wasps), spiders
lace bugs	X	X		X		assassin bugs and pirate bugs, spiders
mealybugs	X	X		X		mealybug destroyer lady beetle
mosquitoes						<i>Bacillus thuringiensis</i> spp. <i>israelensis</i> , mosquito-eating fish
psyllids	X	X		X		pirate bugs
scales	X	X		X	X	<i>Aphytis</i> , <i>Coccophagus</i> , <i>Encarsia</i> , and <i>Metaphycus</i> spp.

						parasitic wasps
slugs, snails			X			<i>Rumina decollata</i> (predatory snail), predaceous ground beetles, birds, snakes, toads, and other vertebrates
spider mites	X	X			X	bigeyed bugs and minute pirate bugs, <i>Feltiella</i> spp. (predatory cecidomyiid fly larvae), sixspotted thrips, <i>Stethorus picipes</i> (spider mite destroyer lady beetle)
thrips	X			X	X	minute pirate bugs, predatory thrips
weevils, root or soil-dwelling				X		<i>Steinernema carpocapsae</i> and <i>Heterorhabditis bacteriophora</i> (entomopathogenic nematodes)
whiteflies	X	X		X		bigeyed bugs and minute pirate bugs, <i>Cales</i> , <i>Encarsia</i> , and <i>Eretmocerus</i> spp. parasitic wasps, spiders

Habitat Manipulation

Plant a variety of species that flower at different times to provide natural enemies with nectar, pollen, and shelter throughout the growing season. The adult stage of many insects with predaceous larvae (such as green lacewings and syrphid flies) and many adult parasites feed only on pollen and nectar. Even if pests are abundant for the predaceous and parasitic stages, many beneficials will do poorly unless flowering and nectar-producing plants are available to supplement their diet. To retain predators and parasites, grow diverse plant species well adapted to the local conditions and that tolerate low populations of plant-feeding insects and mites so that some food is always available.

Other cultural controls that can help natural enemies include reducing dust and properly fertilizing and irrigating. Dust can interfere with natural enemies and may cause

outbreaks of pests such as spider mites. Reduce dust by planting ground covers and windbreaks and hosing off small plants that become excessively covered with dust. Avoid excess fertilization and irrigation, which can cause phloem-feeding pests, such as aphids, to reproduce more rapidly than natural enemies can provide control.

Augmentation

When resident natural enemies are insufficient, their populations can sometimes be increased (augmented) through the purchase and release of commercially available beneficial species. However, there has been relatively little research on releasing natural enemies in gardens and landscapes. Releases are unlikely to provide satisfactory pest control in most situations. Some marketed natural enemies are not effective. Many natural enemies are generalist predators and are cannibalistic and feed indiscriminately on pest and

beneficial species, thereby reducing their effectiveness.

Only a few natural enemies can be effectively augmented in gardens and landscapes. For example, entomopathogenic nematodes can be applied to control certain tree-boring and lawn-feeding insects. Convergent lady beetles (*Hippodamia convergens*) purchased in bulk through mail order, stored in a refrigerator, and released in very large numbers at intervals can temporarily control aphids; however, lady beetles purchased through retail outlets are unlikely to be sufficient in numbers and quality to provide control.

Successful augmentation generally requires advanced planning, biological expertise, careful monitoring, optimal release timing, patience, and situations where certain levels of pests and damage can be tolerated. Situations where pests or damage are already

abundant are not good opportunities for augmentation.

Classical Biological Control Or Importation

Classical biological control, also called importation, is primarily used against exotic pests that have inadvertently been introduced from elsewhere. Many organisms that are not pests in their native habitat become unusually abundant after colonizing new locations without their natural controls. Researchers go to the pest's native habitat, study and collect the natural enemies that kill the pest there, then ship promising natural enemies back for testing and possible release. Many insects and some weeds that were widespread pests in California are now partially or completely controlled by introduced natural enemies, except where these natural enemies are disrupted, such as by pesticide applications or honeydew-seeking ants.

Some Important Parasites of Insects.	Some Important Insect and Mite Predators
Anaphes species Aphidius species Aphytis spp., armored scale parasites Bracon cushmani, grape leafroller parasite Citrus mealybug parasite Cotesia medicaginis, alfalfa butterfly parasite Cottony cushion scale parasite Elm leaf beetle parasite Encarsia formosa, whitefly parasite Hyposoter exiguae, caterpillar parasite Lysiphlebus testaceipes, aphid parasite Tachinid flies Trichogramma spp., egg parasites Trioxys pallidus, walnut aphid parasite	Assassin bugs Bigeyed bugs Brown lacewings Convergent lady beetle Damsel bugs Decollate snail Dustywings Euseius tularensis Green lacewings Mealybug destroyer Minute pirate bugs Multicolored Asian lady beetle Phytoseiulus persimilis Predaceous ground beetles Predaceous midge, aphid midge Sevenspotted lady beetle Sixspotted thrips Soldier beetles, leather-winged beetles Spider mite destroyer lady beetle Spiders Syrphid flies

	Twicestabbed lady beetle Vedalia beetle
	Western predatory mite

Benefits of Biological control

A great benefit of biological control is its relative safety for human health and the environment, compared to widespread use of broad-spectrum pesticides. Most negative impacts from exotic species have been caused by undesirable organisms contaminating imported goods, by travelers carrying in pest-infested fruit, and from introduced ornamentals that escape cultivation and become weeds. These ill-advised or illegal importations are not part of biological control.

Negative impacts have occurred from poorly conceived, quasi-biological control importations of predaceous vertebrates like frogs, mongooses, and certain fish, often conducted by non scientists. To avoid these problems, biological control researchers follow government quarantine regulations and work mostly with host-specific natural enemies that pose low risks and can provide great benefits. As a pest comes under biological control, population densities decline for both the pest and the biological control agent because host-specific natural enemies cannot prey or reproduce on other species.

Dynamics Of Vertebrate Pests

Vertebrate populations are plastic and dynamic, constantly fluctuating in density within limits imposed by their genetic constitution and the characteristics of the environment.. The interacting population stress factors that limit vertebrate densities include emigration, predation, shelter, food, disease,

social interaction. Broadly speaking, the three basic self-limiting procedures that counteract the innate ability of vertebrate pests to produce an even greater surplus of offspring are the interaction of compensatory mortality, reduction in natality, or emigrations. At different times under special conditions, any one of these forces can play the dominant density-regulatory role. Toxic chemicals are utilized to provide compensatory mortality, and the anti fertility action of estrogens provides a reduction in natality . What is needed, if biological control (including anti fertility agents) are to be effective without drastic habitat modifications or use of pesticides, is some self-accelerating method of control that forces populations down by eroding their homeostatic capability. Vertebrates are often acclimatized without any apparent reduction in the densities of other species of vertebrate animals. And, the wider the tolerance of an animal, the greater will be the number of suitable niches available for its survival without any immediate genetic differentiation being required. When a farmer replaces a native vegetation with non native types of forage or cultivated plants (developed in breeding experiments) while of necessity ignoring factors such as natural selection by native animals, he may alter the habitat to such an extent that the native wild animals can no longer exist there. In other instances, the alien forage or crop may stimulate certain native mammals and birds to become so

numerous that they may completely destroy the crop locally. The introduction of alien species may likewise result in the destruction of certain types of native vegetation. The probability that introduced animals disrupt the natural stability of their new habitats depends upon many factors.

Birds

There are about 1,200 species of birds representing 20 orders in India. A total of 63 species of birds belonging to 19 families have been found damaging several crops, mostly grain-yielding and fruit-bearing ones. Grainivorous Birds The important depredatory birds are *Pavo cristatus* (common peafowl), *Grus antigone* (Sarus crane), *Anthropoides virgo* (Demoiselle crane), *Columba livia* (blue rock pigeon), *Streptopelia decaoto* (ring dove), *Psittacula krameri* (rose ringed parakeet), *Psittacula himalayana* (slaty headed parakeet), *Megalaima viridis* (small green barbet), *Sturnus roseus* (rosy pastor), *Acridotheres tristis* (common myna), *Acridotheres giginianus* (bank myna), *Corvus splendens* (house crow), *Macrorhyncus* (jungle crow), *Pycnonotus cafer* (redvented bulbul), *Turodoides striatus* (jungle babbler), *Passer domesticus* (house sparrow), *Ploceus philippinus* (Baya weaver), *Ploceus bengalensis* (black throated weaver bird), *Lonchuria malabarica* (white throated munia), and *Lonchura punctulata* (spotted munia). Oil seeds Bird damage was maximum in sunflower (10 to 90%) and was by rose ringed parakeet and house crow. Ten species of birds caused 3 to 33% damage at sowing and sprouting stages of groundnut. Oil palm was damaged at 3.3 to 30%

by common crow, jungle crow, rose ringed parakeet, and common myna (Rao and Dubey 2006). Management of Granivorous Birds Only non-lethal methods of bird pest management are in vogue. These include suggestions to reverse the trends in crop cultivation by resorting to growing the original crops that were not attractive to birds. For instance, before the introduction of sunflower cultivation in Punjab, parakeets fed on seeds of mulberry and weeds like *Crotalaria medicaginea*, in spite of availability of mature wheat in the fields. Once sunflower cultivation spread, its seeds became very attractive (Saini et al. 1992). By reversing the cropping pattern, the bird damage is expected to be stopped. But such a change is difficult to adapt, as economic and dietary habits of people dictate the choice of sunflower cultivation. A second method is to prevent access to preferred food by wrapping with leaves, as in corn cobs (Dhindsa et al. 1993). Tannins (Feare et al. 1988), and extracts of leaves of *Azardicta indicus*, *Mormoidia foetida*, *Veronica amygdaline*, tobacco, and *Gliricidia sepium* are known to repel bird pests (Rao and Dubey 2006). Treating seeds with Thiram and copper oxychloride at 0.5% before sowing reduced seedling losses to birds in maize, chickpea, soybean, sunflower, and groundnut (Chakravathy 1993). However, such repellents are known to become ineffective in the absence of alternate foods (Feare et al. 1988). Planting seeds deeper to prevent damage to germinating seeds (Dolbeer et al. 1979), growing maize instead of small-seeded cereals, avoiding early and late sowing varieties (Feare et al. 1988), and

growing cucumber along with bottle gourd and creepers in raised basins (Srihari and Chakravarthy 1998) are some of the farming practices to reduce bird damage. Destroying perches and roost sites and denying water can also mitigate the damage. Lure crops, if combined with scares, work more effectively than either of the methods alone (Feare et al. 1988). Planting of fodder sorghum and fodder maize reduced parakeet damage to maize (Rao and Dubey 2006). Scares include pyrotechnics and scarecrows. Growing crops in large blocks also prevented damage by parakeets to sunflower (Rao and Dubey 2006). Frugivorous Birds Several species of parakeets, bulbuls, crows, mynas, and one species of koel are frugivorous. Recorded damage was 20% in apple, peach, and apricot by red billed magpie, red vented bulbul, white cheeked bulbul, and slaty headed parakeet; 14-33% in guava by rose ringed parakeet and small green barbet in Karnataka (Chakravarthy 1993); and considerable damage was caused by bulbuls in Punjab (Toor 1982, Simwat and Sidhu 1973). Losses to grape ranged 19% to 60% in Punjab by bank myna and Indian myna (Toor 1982, Sandhu and Dhindsa 1995), and 36% in Karnataka by jungle crow, common crow, and barbet (Prasad and Verghese 1985). An estimated damage of 21.2% was seen in peach by rose ringed parakeet, common crow, and sparrow (Toor and Ramzan 1974, Mann 1986), and up to 80% damage in apple by blossom headed parakeet (Narang and Chandel 1995). Jungle crow and golden fronted chloropsis caused considerable damage to orange (Chakravarthy 1993), while

common crow was a pest on sapota (Verghese 2006). Rose ringed parakeet (Sridhara 1999), small green barbet, myna spp., and coppersmith (Chakravarthy 1993) damaged pomegranate (10-30%). Reported losses to pineapple due to depredation by jungle crow was 22% (Chakravarthy 1993). Damage to papaya by green barbet (Chakravarthy 1993) and to mango by rose ringed parakeet (Toor 1982) are also reported.

Rodents

Species Of the 128 species of rodents belonging to 46 genera, 12 are serious pests. *Rattus rattus* and *Mus musculus* are the commensals, also occurring in warehouses, godowns, and poultry and livestock facilities. *Bandicota bengalensis* is becoming commensal, replacing *R. rattus* across the country. There are 3 species of arboreal squirrels, namely *Funambulus pennanti*, *F. palmarum*, and *F. tristriatus*. These, along with 2 species of *Rattus*, *R. rattus wroughtonii* and *R. r. blanfordi*, are serious pests of coconut, cocoa, cashew, cardamom, and coffee in south-western and western coastal areas. The arid areas of Rajasthan and north-western Gujarat are infested by 3 xeric species: *Meriones hurrianae*, *Gerbillus gleadowii*, and *Golunda ellioti*. Of these, *M. hurrianae* and *T. indica* cause significant damage. Northeast India is a biodiversity hot spot with its own repertoire of indigenous rodent pests, viz. *R. nitidus*, *R. sikkimensis*, *R. r. brunnesculus*, and *Dremomys lokriah*, apart from *B. bengalensis*, *B. indica*, *M. musculus*, and *M. booduga*. The distribution of mole rat, *Nesokia indica*, is limited to north and eastern India. The

porcupine, *Hystrix indica*, is ubiquitous, occurring at the forest edges, adjacent to crop fields, and wilderness throughout the country. At the northern tip, in the states of Jammu and Kashmir, the rodent species composition is unique with temperate species such as marmots, hamsters, voles, and some indigenous squirrels occurring along with the usual pest complex of *B. bengalensis*, *T. indica*, *M. musculus*, and *Rattus* species. Generally, *B. bengalensis*, *T. indica*, *Millarida meltada*, *Mus platythrix*, *M. booduga*, and *M. musculus* are the agricultural pests throughout the country. Rodent pests in Indian agriculture. Species Distribution Pest status Five-striped northern palm squirrel, *Funambulus pennanti* (Wroughton 1905) South of Sikkim to northern districts of Karnataka. Damage to fruits and vegetables (Prakash et al. 1992, Parshad and Malhi 1994). Southern palm squirrel, *F. palmarum* (Linnaeus 1766) Entire South India. Common pest of chiku, pomegranate (Sridhara 1999), coconut, cocoa, coffee, areca nut, cashew nut & cardamom (Bhat 1992, Chakravarthy 1993). Western Ghat squirrel, *F. tristriatus* (Water house 1792) Limited area of Western and south-western India from Mumbai to Travancore, west coast & Western ghats. Major pest on Cocoa, cashew nut and areca nut (Bhat 1992). The Indian crested porcupine, *Hystrix indica* (Kerr 1792. Throughout India up to 2,750 M. Feeds on tubers, bulbs, tree barks-damage severe at forest edges (Agarwal and Chakravarthy 1992, Sharma 1994, Girish 2005). The Indian gerbil, *Tatera indica* (Hardwicke 1807) Throughout India. Major pest of rain

fed agriculture, consuming almost all crops at every stage (Jain 1992, Sridhara 1999). The desert gerbil, *Meriones hurrianae* (Jerdon) Restricted to north-west Gujarat, Rajasthan desert, parts of Punjab and Haryana. Serious pest of cereals, vegetables and fodder (Prakash 1981). The hairy-footed gerbil, *Gerbillus gleadowii* (Murray 1886) Rajasthan desert and parts of Gujarat. Occasionally becomes a serious pest of crops (Tripathi et al. 1992). The house rat, *Rattus rattus* (Linnaeus 1758) Throughout India as a commensal; as a field pest in plantation crops of S. India and crop fields of N.E. India. Huge losses in godowns, poultry and serious damage in livestock facilities, cocoa, coconut and field crops in N.E. India (Bhat 1992, Sridhara and Krishnamoorthy 1979, Parshad 1999). Sikkim or Hodgson rat, *R. r. brunneusculus* (Hodgson 1845) Restricted to the hill states of N.E. India. Considerable loss to paddy, maize and vegetables. Population outbreak correlated with bamboo flowering (Chauhan and Saxena 1992, Pathak and Kumar, 2001). The Himalayan rat, *R. nitidus* (Hodgson 1845) North-east India & Kumaon region in Uttar Pradesh. Damages paddy, maize and pineapple (Singh et al. 1994). The Wroughton's rat, *R. r. wroughtoni* (Hinton 1919) Kerala, Karnataka, Andhra Pradesh, parts of Maharashtra. Serious pest of coconut, cocoa and oil palm (Bhat et al. 1990). The Norway rat, *R. norvegicus* (Berkenhout 1769) Occurs in only port cities of Mumbai & Kolkatta. Pest of warehouses (Jain et al. 1993). The soft furred field rat, *Millardia meltada* (Gray 1837) Throughout India except north-east

mountains. Serious pest of cereals, pulses and oil seeds. Also damages natural grasslands and fodder crops in Rajasthan (Rana 1992). The Indian bush rat, *Gollunda ellioti* (Gray 1837) North-west region of India. Minor pest of agriculture in Punjab & Rajasthan (Saini and Parshad 1993, Prakash et al. 1995). The house mouse, *Mus musculus* (Linnaeus 1758) Throughout the world. Nuisance in houses, damage in storage and a pest of sugarcane, groundnut (Rao and Balasubramanyam 1992). The brown spiny mouse, *M. platythrix* (Bennet 1832) Throughout India except the north-east, Jammu & Kashmir. Pest of paddy, ragi, wheat, oil seeds, pulses and vegetables (Rao and Balasubramanyam 1992, Sridhara 1999). The Indian field mouse, *M. booduga* (Gray 1837) Throughout India. Pest in paddy, vegetables and groundnut (Rao and Balasubramanyam 1992, Sridhara 1999). The short-tailed mole rat, *Nesokia indica* (Gray 1830) North-western and northern India. Pest on lawn grass, cereals, groundnut and vegetable crops (Ramesh 1992). The lesser bandicoot rat, *Bandicota bengalensis* (Gray 1835) Throughout India including the semi-arid Rajasthan. Very serious pest of cereals, pulses, sugarcane, oil seeds, almost all vegetables, selectively commensal in godowns. Burrowing activity affects fruit trees like apples etc. (Chakraborty 1992, Sridhara 1999, Sridhara and Tripathi 2005). The larger bandicoot rat, *B. indica* (Bechstein 1800) From the south of Rajasthan to the southern tip of India, eastwards to W. Bengal and northeast India. Damage to paddy, wheat, maize and vegetables, also to

aquaculture (Chakraborty 1992). 513 Tripathi 2005). Rodent Damage to Agricultural Crops Almost all cultivated crops are vulnerable to rodent depredation at some stage or the other of the crop growth and maturity. The damage caused is extensive and varied and has been extensively summarized by Parshad (1999) and by Sridhara and Tripathi (2005). Amongst cereals, it was 2.7 to 21.3% in wheat, 3.28 to 24.4% in rice, 10.7 to 80% in maize at seedling stage, 1.9 to 24% in maize at cob formation and maturation stage, and 4 to 10% in sorghum. Species inflicting damage are *B. bengalensis*, *M. meltada*, *M. platythrix*, and *T. indica*. In pulses, damage at seedling stage was 50 to 100% in pigeon pea and 10% in green gram. At pod maturation stage, it was 2 to 7% in pigeon pea, 4 to 18% in cow pea, 5 to 6% in green gram, and 0.6 to 3% in soybean. In oil seeds, damage was 30 to 40% in groundnut seedlings and 70% in sunflower seedlings. Damage was 0.6 to 19% at pod formation and maturation stage of groundnut, which rose to 85% during outbreaks. More than 10% damage was seen in vegetables like tomato, cauliflower, carrot, cucumber, musk melon, bottle gourd, ridge gourd, and chillies. Considerable damage was also seen in knol-khol, potato, pea, cabbage, brinjal, French bean, sweet potato, and sponge gourd. Amongst fruits, rodent damage was 8 to 80% in ber, 2.6 to 44.4% in pineapple, 9 to 19.8% in watermelon, 1.4 to 18.4% in summer squash, 17 to 40% in apple, 1.6 to 17.4% in pecan, 5 to 10% in sapota, and 6 to 12% in pomegranate. Extensive damage was observed in plantation crops: 6.8 to 8% in coconut nursery, 4.5 to 55%

losses to tender coconut, 7 to 15% damage in mature nuts, 10.28 to 60% in cocoa, 1.4 to 20% in cardamom, 10 to 45% to seedling of oil palm, and 50 to 57.3% to fruits and nuts of oil palm. However, damage to cashew nut and rubber were negligible. Strategies of Rodent Pest Management In spite of various methods of control (Table 2), rodent damage continues to be unabated in India. Not only is pest density high, but there are several species with varying biological traits and behavioural ecology infesting the crop simultaneously or at different stages of its growth, in what appears to be a successful example of resource partitioning, both temporally and spatially. Managing these multiple species of rodent pests, and motivating farmers to adopt crop- and area-specific management techniques, needs evolving appropriate technologies, preferably integrated ones. The various methods in practice can be categorized into 4 major approaches, namely preventing rodent access to crop fields, discouraging infestation, reducing numbers, and preventing re-infestation and population build-up. Preventing Access Preventing access to crop fields is mainly by rendering fields unfit for fresh burrows, reducing vegetation cover so that exposure to predators is increased, and erecting barriers. Changes in tillage practices such as deep tillage, crop rotation, ploughing the vacant bunds and land around wheat fields (Ramesh and Katiyar 1985, Parshad 1999), and keeping bunds low and narrow (Sharma and Rao 1989) are some of the measures advocated to prevent rodent access. Discouraging Infestation

Discouraging infestation by eliminating or reducing sources of food and harbourage was achieved by synchronized cropping, clean cultivation, and by weed control (Singh et al. 1983, Sablok and Pasahan 1985, Pasahan and Singal 1994). But attempts to raise rodent resistant varieties are non-existent in India The burrows are flooded or smoked to force rats out, which are caught by hand or by using nets, or killed by sticks, or dogs are allowed to hunt them. Several tribes in south India, Bihar, and north-east India catch rats to use as food Sl. No. Strategy Steps/Technology to be Adapted 1. Preventing access to crop fields (i) Tillage (ii) Bund reduction (iii) Agro forestry (iv) Barriers 2. Discouraging infestation (i) Synchronized planting (ii) Clean cultivation (iii) Resistant varieties 3. Density reduction (i) Biological control (a) Predators (b) Pathogens and diseases (iv) Fertility control (a) Steroids (b) Immunocontraception vaccines (c) Predator odours 4. Integrated pest management of rodents (i) Understanding pest species (ii) Action threshold (iii) Population dynamics (iv) Management (a) Prevention of infestation (b) Non lethal or weak chemical use (c) Pesticide application 514 (Whitaker 1979).

Bats

Only 3 of the 12 species of fruit bats are common throughout the country, namely the short-nosed fruit bat, *Cynopterus sphinx* (45 g), the fulvous fruit bat, *Rousettus leschenaulti*, and the Indian flying fox, *Pteropus giganteus* (900 g). Studies on bat damage to fruits are limited. *C. sphinx* is reported to damage grapes substantially, which

was positively correlated with fruit maturity and was higher if the vineyard had open spaces around it (Verghese 1998). Damage ranged 10-100% (Srinivasalu and Srinivasalu 2001) and yield loss was 1,182 kg/ha by *P. giganteus* and *R. leschenaulti* (Elangovan and Marimuthu 2001). *P. giganteus* damaged 18% of areca nut (*Areca catechu*) and 12.5 to 22.3% of sapota, while *P. giganteus* along with *C. sphinx* damaged 18% guava (Chakravarthy and Girish 2003). The most practical and harmless method of bat management is netting entire trees with fine-mesh fishing net. In larger orchards, mist nests are used to capture them. Eco-friendly, economical methods include covering grape bunches with dry sprigs of foliage, leaving batdamaged bunches on the vine intact (Verghese 1998), and using firecrackers (Srinivasalu and Srinivasalu 2001). Block plantation makes it easy to cover fruit-bearing trees and vines with nylon nets or sprigs, dry foliage, thatch, etc. (Chakravarthy and Girish 2003). Growing trap crops like Singapore cherry, *Muntingia calabura*, in and around orchards can divert bats away from commercial fruit crops (Chakravarthy and Girish 2003, Marimuthu 2004).

Blue Bull

Blue bull, *Boselaphus tragocamelus* (Artiodactyla: Bovidae) is indigenous to India, with its distribution restricted to western and northern India. It is the biggest antelope in the country (2 m in length and 1.5 m in height), inhabiting areas with open scrub and scarce vegetation in and around wildlife sanctuaries, but avoids dense forests. An adult animal is reported to consume 13- 15

kg plant material per day (Goyal and Rajpurohit 2000). Of late, crop depredation by blue bull has become a serious problem in the states of Rajasthan, Haryana, and Punjab. However, such studies are limited to surveybased data collection. In Haryana (north India), gram, wheat seedlings, and green gram rarely were damaged less than 10%, and often damage reached as high as 58% of total yield (Chauhan and Singh 1990). In Madhya Pradesh (central India), damage was reported for gram, green gram, wheat seedlings, mustard, linseed, groundnut, sugarcane, soybean, gingilly, and jowar. In certain areas, the damage was so severe that cultivation had to be abandoned (Chauhan and Sawarkar 1989). The blue bulls in Rajasthan preferred moth (*Pennisetum aconitifoliosum*), gawar (*Cyamopsis tetragonoloba*), bajra (*Pennisetum typhoidenum*), moong (*Triticum vulgare*), jeera (*Carum nigrum*), dhanian (*Coriandrum sativum*), and several vegetables. In addition, fruits like ber (*Ziziphus maritima*), nimbu (*Citrus medica*), papita (*Carica papaya*), amrud (*Picidium guajava*), and anar (*Punica granatum*) were also devoured. Several reasons are attributed to the pestiferous activities of blue bull, such as rapid increase in population consequent to a ban on hunting and trapping, protection bestowed by the Wildlife Act of 1972 (Chauhan and Sawarkar 1989), lack of natural predators, deforestation, overgrazing of grasslands by livestock, and religious protection given by a sect of Hindus called Bishnois who share the same habitat as blue bull. The only method of crop protection was the guarding of fields by humans and

dogs during vulnerable stages of crop growth. Although culling was suggested, it was strongly opposed by Bishnois. In view of strong demands by affected farmers, the governments of Haryana and Rajasthan have relaxed rules of hunting, even though the animal is a protected species. Other methods, such as containing them in enclosures, fencing crop fields including power fencing, translocation, and sterilization, are not practical and economical for the marginal farmers of India.

Monkeys

In dealing with the rich primate fauna of India, we face the dilemma of conserving rare and endangered species of primates (such as Assamese pig-tailed and stump tailed macaques; capped, golden, and Phayre's langurs; slow loris and Hoolock gibbon in north-east India; and lion tailed macaque, Nilgiri, langur, and slender loris in south India) on one hand, and managing the pestiferous activities of monkeys on the other hand. Three species of monkeys, viz. rhesus monkey (*Macaca mulatta*), bonnet monkey (*M. radiata*), and Hanuman langur (*Semnopithecus entellus*), although living in forest edges, are almost totally dependent on the human environment for food, and they become pests in the process. Long-term studies on rhesus macaques have revealed vigorous population growth by prolific breeding and efficient utilization of commensal habitat, thus qualifying them for 'r' selection. They are also termed "weed macaques" because of their aggressive commensalism. Hanuman langur (*Semnopithecus entellus*), in spite of being a successful

commensal, has a lower birth rate and high infant mortality. In the wild, they subsist on natural vegetation such as seeds, nuts, fruits, grasses, leaves, roots, occasionally insects, and rarely raid crops. As they are considered as the incarnation of Hindu Monkey God, Hanuman, devout Hindus feed them reverentially. It is only at the fringes of some forests, protected areas, and sanctuaries that they become pests, raiding cultivated foods, eating everything that is palatable (i.e., sown seeds, sprouting seedlings, young plants, maturing green vegetables, and fruits. This apart, there was significant loss due to consumption of flowers and fruits, and by way of damage to vegetative parts of trees. Sixty percent of the farmers guarded the crop fields to prevent langur damage during season. Twenty percent used a device of throwing stones, 15% employed dogs to chase monkeys, while the remaining 5% used lethal approaches such as shotgun, potash bomb, and high voltage electric current. Rhesus monkey (*Macaca mulatta*) lives close to human beings in villages, towns, cities, temple sites, parks, gardens, orchards, etc. Out of 0.3 million monkeys reported to live in India, around 48.5% are *M. mulatta*, which are true commensals (Southwick and Siddiqui 1994). The problems associated with rhesus monkeys are three-fold, namely possible transmission of fatal diseases, nuisance to people, and pestiferous activities. With their natural habitat destroyed, fragmented, or shrunk, rhesus monkeys are forced to raid human habitat to procure food and water. They invade crop fields and

settlements, damaging property, gardens, household items, etc. They are over-abundant in temples, hospital premises, and schools. Irrate citizens threaten nuisance monkeys, hit them with stones, and sometimes even shoot at them, which makes monkeys defensive and overaggressive. In response, they threaten human beings with snarls, snatch food boxes, handbags, umbrellas, and spectacles. Frequently, they bite; bites have increased alarmingly to 100 bites a day in New Delhi alone (Malik 2001). Southwick and Siddiqi (2001) suggested 3 measures to reduce monkey menace: reducing supplemental feedings, translocation, and fertility control. However, supplemental feeding by religious Hindus will never stop in India, and fertility control is yet to find a safe, successful technology. Thus, translocating becomes the only feasible and practical method to manage problem monkeys (Siddiqi and Southwick 1993, Imam and Malik 1997).

Unconventional And Sporadic Vertebrate Pests

There are a few herbivorous and omnivorous mammals that become sporadic pests. These include some species of monkeys, bears, wild boar, jackal, hare, and peacock. Langurs Three species of indigenous langurs, viz. Phayre's leaf monkey (*Presbytis pharyrei*), capped langur (*Presbytis pileatus*), and golden langur (*Presbytis geei*), which normally live in dense forests of north-east India, have learnt to raid crops. They have started feeding on ripe fruits, green twigs, green leaves, flowers, pods, seeds, fleshy fruits of mango, pigeon-pea, *Zizyphus*, *Brassica* spp.

(cabbage), citrus, guava, banana, jackfruit, and gooseberry (*Embelica*), resulting in considerable losses in orchards (Bhattacharjee and Chakravorthy 1992). Sloth Bear The sloth bear, *Melurus ursinus* (Carnivora: Ursidae), is indigenous to India. In the natural habitat, the sloth bear's diet consists of fruits of banyan, wild figs, mangoes, jamoon, ber, honey, and termites. In several places, particularly Karnataka in the south, changes in forest type from dense forests to plantation and scrub jungle, and encroachment of agriculture up to forest edge/ foothills, have reduced food availability and the range of 518 bears, forcing them to depredate on agricultural crops. Ishwaraiah (1984) reported that 50% of the sloth bear's nutritional requirements are met from crop fields because of non-availability of natural food in their habitat. Apart from crop losses, bear-man conflicts are also on the rise. There are no studies on bear management so far. Wild Boar Wild boar, *Sus scrofa* (Artiodactyla: Suidae), found throughout India, is an unrecognized pest of crops wherever wilderness borders cultivation, moreso around national parks and hilly regions. A total of 44 species of edible plants in Kerala were reported to be destroyed by wild vertebrates such as elephant, wild bison, sambar, wild boar, bonnet macaque, common langur, black napped hare, and pea fowl, with wild boar causing the maximum damage (Jayson 1999). Wild boar damage also occurred in crop fields around national parks of Sariska (Sekhar 1998), Nandadevi Biosphere (Rao et al. 2002), and Kumbalgarh Wildlife Sanctuary (Chhangani and

Mohnot 2004). It is a pest on cardamom and rice in Karnataka, causing 12% loss in the latter when grown along forest fringes (Chakravarthy and Srihari 2002, Chakravarthy 1994), with taller varieties being damaged more than dwarf varieties (Thomas and Naidu 1995). Hanging polythene bags containing thimet granules and sand along the edges of rice fields (Chakravarthy and Srihari 2002), growing dwarf rice with long auricles on panicles (Thomas and Naidu 1995), guarding fields (Chhangani and Mohnot 2004), and cultivating non-edible crops (Rao et al. 2002) are some of the measures adopted to contain wild boar damage. Golden Jackal The golden jackal, *Canis aureus* (Carnivora: Canidae), lives close to towns, villages, and cultivated areas at the fringe of forests. Although they feed on crops such as corn, sugarcane, melon, and seeds of pulses (Chakravarthy 1994). Due to religious sentiments and the protected status of the peacock, which is also the national bird, no measures are taken to discourage peacocks from foraging in cultivated fields.

Conclusion

The management of vertebrate pests in India is besotted with diverse opinions and pressures. In many situations, methods to deal with vertebrate pest problems are limited. Local, national, or international regulations and laws interfere with implementation of management of their pestiferous activities. Research and concern has resulted in several recommendations to prevent damage. However, the choice of method is riddled with controversy and is susceptible to social,

economical, and political pressures. Those suffering damage insist on the traditional methods of hunting, trapping, and poisoning. But these age-old practices are considered cruel and inhumane by conservationists and the emerging animal rights/welfare activists. But when planning management, it is important to bear in mind that usually these protesters are not victims of vertebrate damage, directly or indirectly. In the end, an Integrated Vertebrate Pest Management is the best approach for resolving the problems with avoidance of lethal methods as much as possible.

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