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There are few forested areas in the world in which rodents are not a pest. Forests, nurseries, and plantation crops are frequently damaged by one or more rodent species. Damage by rodents includes seed consumption, seedling damage, debarking, root damage, fruit damage, and secondary damage caused by pathogens. This paper is a summary of the agroforest rodent damage and control efforts used in Africa, Asia, and Latin America.

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RODENT PROBLEMS AND CONTROL IN AGROFOREST SYSTEMS

by

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Rodents are small, gnawing mammals that belong to the order Rodentia. There are almost 1,700 species, characterized, with few exceptions, by two upper and two lower incisors (Nowak and Paradiso, 1983). Canine teeth or anterior premolars are absent, leaving a space (diastema) between the incisors and molars. Agroforest damage problems result from the use of these incisors to cut, bite, or gnaw vegetation or trees.

Much variety exists within the order Rodentia. Size ranges from very small (5-7 grams) to very large (more than 50 kg) animals. Habitats range from subterranean to arboreal, from swamps to deserts; and distribution varies from sea level to high mountains. Rodents are grouped into one of three general types - squirrels (Sciuromorpha), rats (Myomorpha), and others (Hystricomorpha). The sciuromorphs can be arboreal (tree squirrels), fossorial, or terrestrial (ground squirrels) as can the myomorphs--the rat-like group which includes all those rodents that resemble typical rats and mice. The third group includes a mix of other rodent types, namely porcupines, mole rats, and cane rats. Food habits also vary with some being mostly vegetarian (herbivorous), mostly insect-eating (insectivorous), or a combination of several food types (omnivorous).

Because of the variety of rodent habitats and habits and their worldwide distribution, there are few forested areas in the world in which rodents are not a pest. Forests, nurseries, and plantation crops are frequently damaged by one or more rodent species. The following is a summary of the agroforest rodent damage and control efforts used in Africa, Asia, and Latin America.

TYPES OF AGROFOREST RODENT DAMAGE

Damage can occur at any crop stage, from seed to the mature tree or fruit. Specific susceptibility will depend on the tree and/or rodent species present. A summary of reported rodent damage is given in Table 1.

Seed consumption. Seeding is a very cost effective method used in reforestation projects (Dalmacio, 1974). Unfortunately, losses can be very high when seed-eating (graminiferous) rodents are present (Prakash et al., 1967). Even low to moderate pest rodent populations can cause significant losses since seeds are readily exposed to daily feeding over a long period of time. Rodents are generally opportunistic, and when seeding provides an abundant source of food, they readily take advantage of the situation. Seeds are very nutritious, providing ample protein and carbohydrates at levels usually not found in other plant parts. Some rodents may even gather and store seeds in caches for later consumption.

Seedling damage. Transplanting seedlings from a nursery to the field eliminates seeding losses, provided the nursery is protected from rodent pests. The method, however, is labor-intensive and costly compared to seeding. Expensive seedlings can be damaged in the nursery or field by root cutting (fossorial rodents), stem cutting, plant pulling, or complete consumption of above-ground parts by rodents. If the seedling can mature to a sapling stage (up to 10 cm diameter), some tree species may avoid further attack by rats. However, many plants or trees are most susceptible to damage the first year. One year is a lengthy susceptible period and losses can be severe enough to warrant replanting.

Debarking. The removal of bark, including the cambium layer, can result in reduced growth, secondary damage (fungi), lower fruit production, and death, depending on the severity of damage. Debarking can occur at ground level, resulting in girdling of the trunk by terrestrial rodent pests or at upper levels by arboreal rodent pests. When tertiary branches or terminal shoots are gnawed on, the pulp may be removed or branches severed by the cutting incisors of rodents.

Debarking may be seasonal reflecting a rodent behavioral response to the environment or a nutritional response by the rodent to a physiological change in the plant. Tree squirrels, porcupines, and a variety of rat-like rodents, both terrestrial and arboreal, are responsible (Kuo and Liao, 1986; Parry, 1952; Rodriguez and Herrera, 1984; Ruhm, 1966; Udagawa, 1968).

Root damage. Fossorial or burrowing rodents attack the tree from underground by girdling, cutting, or completely destroying parts of the root system. The tree gradually deteriorates, resembling damage caused by other pest or agronomic problems. When burrow openings are readily visible near damaged trees, rats should be suspected as a cause. When burrows are not readily observed, digging and inspecting exposed root systems may be necessary to determine if rodents are responsible.

Fruit damage. Mature forests usually produce enough seeds, nuts, or unharvested fruit that damage (fruit consumption) does not adversely affect the agroforest system. However, plantation crops grown specifically to harvest fruit can be significantly damaged (Fiedler et al., 1982; Lenton, 1980). Cacao, coconut, papaya, oil palm, macadamia

nuts, citrus, and others have received heavy losses warranting investments in rodent control to limit damage.

Secondary damage. A result of direct damage may be the invasion of pathogens, particularly fungi, bacteria, or viruses. This secondary damage could be much more significant than the primary damage caused by rodents. Rodents may potentially introduce these pathogens as they traverse from tree to tree, but more traditional routes, such as wind or insects, are more probable.

Summary of rodent damage. Beneficial effects of rodents should not be overlooked. Some rodent pests consume pest insects and may actually play a role in reducing insect damage. Some rodents may bury seeds or transport fruits containing seeds to areas favoring germination or seedling development. The significant agroforest/rodent problems, however, are characterized by losses that far outweigh these potential beneficial effects. These conflicts usually involve damage to seeds, seedlings, or young trees, and to fruits of plantation crops (Ganguli and Kaul, 1962; Hechter-Schulz, 1962; Hopf et al., 1976; Sanchez, 1967).

When previously undisturbed areas are opened up for forestation projects or for introducing plantation crops, a "new area" phenomenon may occur (N.A.S., 1975). This results when a more diversified environment (with low numbers of each rodent species present) is changed to a simpler habitat surrounded by a favorable edge environment. The numbers of pest (and nonpest) rodents invariably increase in response to these changes which produce more favorable rodent habitat (food and shelter). Thus, porcupines, normally scattered in West African forests, will be attracted to a cleared area and damage plantation crops.

PROBLEM IDENTIFICATION AND ASSESSMENT

The mere presence of a rodent in an area being damaged does not necessarily mean it is responsible. It must be collected, identified, and verified as a pest or capable of damaging the plant in question. Snap-traps are commonly used to collect specimens. Often, several rodent species will be present in a problem area requiring a substantial effort to determine which are pests (Rana, 1983). This is important however, since the selection and efficacy of a control method(s) will depend on proper identification of the species and definition of the problem.

Relative abundance or activity of a rodent pest species can be determined by (1) signs (tracks, feces, runways, burrows, damage or nests), (2) snap-trapping (percent trap success), (3) tracking boards or tiles (percent marked or tracked tiles), or (4) bait-censusing (amount of a known quantity of bait consumed by rats over a given time period). Abundant information used in combination with a damage assessment will provide justification for the degree of control effort that may be required.

Well-known rodent/agroforest problems can be quickly defined and assessed, but lesser known problems may require substantial time and effort. For example, seedlings clipped at the base resulting in total loss for that plant will be easy to damage assess. However, damage resulting in only partial losses or losses modified by plant compensation will be more difficult to assess. In constructing cost:benefit evaluations of control efforts, assessments showing reduced rodent populations and damage and increased yield (or harvest) are necessary to adequately demonstrate success or cost-effectiveness.

MONITORING AND FORECASTING

Pest rodent populations are subject to cyclical changes brought about by variability in the availability of basic needs (food, water, and shelter). When these needs are readily available, reproduction is increased. Immigration by rats from surrounding, less favorable habitats also increases numbers of pest rodents. Rainfall and irrigation provide water and increased vegetation (shelter and food) that favor increased rat populations. In contrast, dry seasons or droughts result in mortality of and emigration by rats, resulting in smaller populations and less damage.

Seasonal damage patterns are, therefore, not uncommon and somewhat predictably related to weather or availability of susceptible crop stages. An appropriate monitoring program, for example, could identify more susceptible and less susceptible planting times; or time periods for implementing a prophylactic control strategy to reduce predictable damage. Monitoring in its simplest form would involve periodic estimations of pest rodent numbers and their damage.

CONTROL OR RODENT PEST MANAGEMENT

Biological methods. Although predation as a control tool has only a limited effect on rodent populations, one example resulted in measurable positive results. By increasing nest boxes of Asian Barn Owls (*Tyto alba*) in a Malaysian plantation crop, rodent pests and damage to oil palm were reduced (Lenton, 1980). In Alberta, brush piles were added to reclamation sites to establish more weasels, a predator of small mammals (Pauls, 1986). A far more profitable method involves modifying a habitat to favor tree crops and discourage rodent pests. Reducing or removing vegetation decreases cover that rats use to avoid predation and as an alternative food source. Plowing, cutting or burning 'weeds' also reduces competition and possibly other pest problems such as insect damage to tree crops. Using resistant tree varieties which are less susceptible to rodent damage is a possible control technique but not yet a reality. This is primarily due to economic or marketing factors which override decisions to manipulate tree selection to reduce damage (N.A.S, 1975; Udagawa,

1968). The growth period of known resistant varieties is simply too long.

Physical methods. Popular, but laborious and generally not effective, describes most physical methods for rat control. Digging or flooding burrows to catch rats is done throughout the world. Trapping with many different kinds of traps--some familiar, others locally constructed--also occurs worldwide. Rat drives, using lines of humans or simply burning vegetation, are used to capture terrestrial rodent pests. Barriers constructed from natural or synthetic materials are designed to prevent access to individual trees (banding) or small groups of trees (exclosures in nurseries). The use of plastic mesh cylinders (trade name Vexar) has protected seedlings from rodent damage in Alberta (Pauls, 1986) and the western U.S. (Anthony et al., 1978). However, attempts in the Philippines to reduce rodent damage to ipil-ipil seedlings with the cylinder were unsuccessful (Fiedler et al., 1982). Shooting, particularly tree squirrels, is another method used. It probably has more sport value than cost-effectiveness.

Chemical methods. Acute toxicants, or rodenticides that kill after a single ingestion of a lethal dose of treated bait, have involved almost exclusively the use of zinc phosphide. Good availability and low cost, plus a familiarity due to decades of use throughout the world, are primary reasons for its popularity. Quick action of the toxicant produces immediate, noticeable results in visibly dead or dying rats. Occasionally, reports of hazardous misuses of acute toxicants, such as endrin mixed in a paste and applied to tree trunks, are made. These kinds of dramatic attempts are not only dangerous to humans and other nontarget species, but their efficacy has yet to be experimentally demonstrated. Their use should not be encouraged.

Chronic toxicants, or rodenticides that require several consecutive feedings of treated bait, have almost exclusively involved warfarin. Warfarin is more available than other chronic anticoagulants and probably more familiar to users because of about three decades of worldwide use. A variety of other chronic anticoagulant rodenticides and, more recently, second-generation anticoagulants, which require only a single feeding to cause death in 6-8 days, have been occasionally available.

Fumigants, chemical products designed to introduce toxic gases into rodent burrows, have rarely been used in agroforest systems. Calcium cyanide, aluminum phosphide, and phosphorous (alone or in combination with other flammable, toxic, gas-forming substances) have been popularly used elsewhere, but usually not in tree crops. Cost-effectiveness in tree crops is most likely not good, but this needs to be demonstrated.

Repellents have been used to protect seeds, seedlings, and saplings in developed, temperate countries (Besser and Welch, 1959; Martell, 1935; Peters, 1974), but not in developing countries of the tropics. A good seed protector chemical should reduce rodent consumption by 80

percent, be chemically stable, nonphytotoxic and inexpensive, and have low toxicity and an adequate margin of environmental safety (Kverno, 1954). An added benefit would include effectiveness against pathogens and insect pests.

Summary of control methods. Rodent pest control in tropical or subtropical agroforest systems traditionally has involved chemical baiting, using zinc phosphide mixed with a locally available grain bait. To a lesser extent, warfarin, also mixed in grain or a commercial wax-block formulation, has been used. For poor climbing rodent pests, barriers or fences limiting access to nursery plants have been used. Wire-mesh or metal sheets have been installed when climbing rodent pests were present. To my knowledge, none of these techniques have been fully evaluated in order to determine cost-effectiveness in nontemperate-zone tree crop situations.

DISCUSSION

With few exceptions, rodent damage and control in tropical agroforest systems has not been well defined. For a given problem situation, it very well may be necessary to describe and quantify the damage or loss and to identify the damaging rodent species. Provided local expertise is not available, technical assistance may be necessary to assist local counterparts in carrying out these important initial steps. Seasonal damage patterns and susceptible crop stages of affected plants, if recognized, will be extremely helpful in developing a management strategy. Damage assessments that directly measure such adverse effects (i.e., percent lost seed or cut seedlings; dead saplings or debarked saplings per hectare; or other quantities that can be converted into economic loss estimates) are useful. When partial damage occurs, a new damage assessment technique may need to be researched and developed in order to estimate monetary losses.

Identifying the rodent species can be accomplished by trap collections (snap-trap) and study skins, being alert to the fact that some pest species are diurnal and require daytime trap setting. Population density estimates and reproductive activity (percent pregnant females) could be estimated from trap lines or grids set in problem areas. Stomach collections preserved in alcohol or formalin could provide additional information to confirm a damaging species and its food habits.

Preliminary control trials comparing one or more potential or known methods against untreated plots should be completed prior to recommending any large-scale control efforts. For lesser understood problem situations, a period of research activity may be necessary to determine potential control methods. This may be difficult enough to require technical assistance or support.

Finally, a monitoring program designed to anticipate seasonal peaks or cyclical outbreaks could provide the lead time necessary to implement effective control efforts. After several years of such experience it may even be possible to establish an economic threshold value (number of rats/ha, percent females pregnant, damaged trees/ha, or a combination of these indicators) that would trigger prophylactic control efforts to begin. Simply waiting for significant damage to occur, then baiting, usually results in ineffective control efforts that waste time and money.

Rodent control programs are a significant part of commercial forest production programs--mostly in developed countries. This is because the potential economic losses caused by rodents are recognized and effective control programs implemented to limit these losses. Reforestation projects and vital plantation crops that provide fuel and food, respectively, are no less important in Third World countries. Thus, rodent/agroforest problems should not be neglected at the expense of economic development.

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Table 1. A Summary of World Forestry and Plantation Crop Rodent Damage

Plant	Country	Species	Damage	Control
		WEST AFRICA		
Oil palm	Nigeria Cameroon	Tatera kempi, Thryonomys swinderianus, Praomys (Mastomys) natalensis, Dasymys incomtus, Lemniscomys striatus, Lophuromys sikapusi, Oenomys hypoxanthus	1-3 year seedlings; apical bud consumed; ripening fruit: worse near boundaries with bush	Wire collars; ZnP painted on; baiting ZnP & warfarin or warfarin wax block
Cacao	Nigeria West Cameroon Ghana Sierra Leone	Squirrels (Funisciurus anerythrus and Heliosciurus gambianus), T. swinderianus, Graphiurus hueti, Cricetomys gambianus, Stochomys longicaudatus, Grammomys rutilans, Praomys tullbergi	Seedlings, pods	Warfarin and copper fungicide
Cassia siamea	Sierra Leone	Thryonomys sp.	Seedlings	Fence of palm fronds and sticks
Havea sp. (rubber)	Sierra Leone	Thryonomys sp., P. tullbergi	Saplings debarked; germinating seeds	Fencing; clearing bush
Pinus caribbea	Sierra Leone	Ground squirrel	Seedlings uprooted	Fencing with palm frond
		CENTRAL AFRICA		
Cupressus lindleyi (cypress trees)	Malawi	--	1-2% damage ring-barking	Clearing undergrowth
Pinus kesiya, P. oocarpa	Zambia	--	Nurseries	Warfarin bait

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		NORTH AFRICA		
Olive, almond, pistachio	Tunisia, Morocco	*Meriones shawi*	Debarking; root damage	Strychnine, zinc phosphide, and α-chloralose rodenticides
Dates	Egypt	*Jaculus orientalis*	Fruit	--
		SOUTHERN AFRICA		
Coniferous plantations	South of Zambezi River	*T. swinderianus*, *Rhabdomys pumilio*, *Otomys irroratus*, *O. laminatus*	Ring-barking <3-year-old trees	Warfarin bait; clearing bush; trapping
Apple trees	Zimbabwe	*Cryptomys hottentotus*	Root damage; underground girdling	--
Paw paws	Zimbabwe	*Hystrix* sp.	10% young stems chewed	Spring traps
		EAST AFRICA		
Gmelina aborea	Uganda	*Xerus erythropus*	Nursery seeds	None
Cypress and pine	Uganda	*Otomys* spp., *Lophuromys* spp.	10-20% damage of young trees ring-barked	Slashing; hoeing; low pruning
"	Tanzania	*Thryonomys* spp., *Cricetomys* spp.	Ring-barking, eating roots	Warfarin bait
"	Kenya	*R. pumilio*, *Lophuromys* sp., *T. swinderianus*, *Oenomys hypoxanthus*	Debarking	Sanitation
Coffee, tea, enset	Ethiopia, Kenya	*Tachyoryctes splendens*	Root damage	Flooding burrows

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		SOUTH ASIA		
Forest trees, seedlings	Bangladesh	Cannomys badius	--	--
Shrubs and trees	India	Meriones hurrianae	Seeds	--
Euphorbia caducifolia, Capparis decidua	India	Rattus cutchicus, Mus cervicolor	Flowers	ZnP baiting; aluminum phosphide fumigation
Acacia senegal, Anogeissus pendula, Commiphora wightii, Salvacera deoides	"	"	Saplings	"
Albizia lebbek	"	M. hurrianae, Tatera indica	Debarking	"
Prosopis cineraria	"	Gerbillus gleadowi, M. hurrianae	Debarking	"
Acacia tortilis	"	G. gleadowi, T. indica, M. hurrianae	Debarking; saplings cut completely	"
		SOUTHEAST ASIA		
Oil palm	Malaysia	Rattus tiomanicus, R. rattus, R. argentiventer R. rattus diardii, R. exulans	Maturing fruit	Warfarin wax blocks; warfarin bait; ZnP bait; endrin paste; wire netting
		Callosciurus notatus, C. caniceps	Maturing fruit	Shooting and bounties; border brush removal
		Hystrix brachyura, Trychis lipura (occasional)	Seedling	--

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		SOUTHEAST ASIA - continued		
Rubber	Malaysia	*Hystrix* sp.	Seedling	Trapping; poison baiting
Coconut	Philippines	*Rattus rattus mindanensis*, *R. exulans*	Immature nuts	Clean cultivation; trapping; baiting; banding
	Thailand	*R. rattus*, *R. exulans*	Immature nuts	Mechanical exclusion; chemical baiting
	Malaysia	*C. notatus*, *Lariscus insignis*	Immature nuts	Trapping; shooting
Leucaena leucocephala (Ipil-ipil)	Philippines	*R. r. mindanensis*, *R. exulans*, *R. argentiventer*	Seedlings cut; saplings debarked	Baiting
Pinus kesiya (Benguet pine)	Philippines	Field rodents	Seeds	Repellents
Cacao	Malaysia	*Callosciurus prevosti*, *Sundasciurus hippurus*, *Rattus mulleri*	Maturing pods	Trapping; shooting; some baiting
Acanthocephalus chinesis	Malaysia	*Rattus rattus jalorensis*	Seedling, stems	none
Pinus spp. and *Swietenia macrophylla*	Malaysia	Mice	Seeds	In nurseries--wire mesh exclusions; in plots--baiting
Agathis macrophylla (Kauri pine) *Gonystilus hancanus* (ramin) *Shorea mucrophylla* (illipenut)	Malaysia	*Rattus* sp.	Nursery seeds	None

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		SOUTHEAST ASIA - continued		
Coffea robusta (coffee)	Philippines	*Rattus everetti*	Branches cut, stripped, or girdled during flowering period	Baiting, 0.025% warfarin in rice
		OCEANIA		
Coconut	Most islands	*Rattus rattus*, *R. exulans*	Immature nuts	Banding; warfarin or zinc phosphide baiting; brush removal
Cacao	Melanesia, Fiji	*R. rattus*, *R. exulans*	Maturing pods	Baiting
Pine trees	Society Islands	*R. rattus*	Stems attacked in young plantations	Baiting
Anise trees	--	*R. exulans* (?)	--	--
		AUSTRALIA AND NEW ZEALAND		
Araucaria cunninghamii (hoop pine)	Australia	*Rattus culmorum*, *R. fuscipes*	Root bark of trees <8 years chewed	Baiting
		WEST INDIES		
Coconut	Jamaica, St. Lucia	*Rattus rattus*	Maturing nuts	Banding; baiting
	Trinidad	Squirrels and rats	Maturing nuts	Hunting; shooting
Cacao	Dominica, Dominican Republic, Jamaica, St. Lucia	*R. rattus*	Maturing pods	Baiting
Coffee	Dominican Republic	--	Beans (or berries)	--

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		LATIN AMERICA		
Oil palm	Brazil	Field rats	Stem of young plants	None
	Peru	Murids	Stem of young plants	Baiting; metal exclusion
Rubber	Brazil	*Dasyprocta aguti*, *Cuniculus paca*	Bark of young seedlings and buddings	None
	Mexico	*Geomys mexicanus*, *R. rattus*	Roots	None
Cacao	Brazil	--	--	--
Coffee	Mexico	--	--	--
Inga (shade tree)	Mexico	--	--	--
Pinus radiata	Chile	*Octodon bridgesi*	Young trees	--
Araucaria angustifolia	Brazil	*Agouti* sp., *Sciurus* sp., *Rattus* sp.	Seeds	--
		ATLANTIC		
Wild guava	Ascension Island	*R. rattus*	Fruit (no direct economic loss)	None
Papaya, guava, peach, plum, wild olive, and *Acacia* spp.	St. Helena	*R. rattus*, *R. norvegicus*	Roots and fruit; tips of *Acacia* spp.	Baiting
Apples, peaches, plums	Tristan da Cunha	*R. rattus*, *Mus musculus* (?)	Fruit	Baiting

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		FAR EAST		
Larix leptolepis (Japanese larch) *Chamecyparis obtusa* (Hinoki cypress) *Pinus densiflora* *Cryptomeria japonica* (Sugi cedar)	Japan	*Clethrionomys rufocanus*, *Microtus montebelli*, *Eothenomys smithi*	Debarking young trees (<10 years)	ZnP baiting
Cryptomeria japonica (Japanese cedar)	Taiwan	*Callosciurus erythaeus*	Debarking	Chemical poisoning; weeding; thinning
		UNITED STATES		
Forestry	USA	*Pitymys pinetorum*, *Sciurus niger*, *Sciurus carolinensis*, *Sigmodon hispidus*, *Tamias striatus*, *Castor canadensis*, *Myocastor coypus*, *Geomys bursarius*	Girdling of trunk and roots of seedlings and mature trees	Trapping; habitat alteration; baiting; repellents
		EUROPE		
Tree nurseries	Norway, Britain, Denmark	*Microtus agrestis*, *Clethrionomys glareolus*, *Rattus norvegicus*	Browsing and bark-stripping	Trapping; baiting
Conifers	Norway, Sweden	*M. agrestis*, *M. savii*, *Arvicola terrestris*, *C. glareolus*	Girdling of stems	Baiting; trapping; fencing
	Italy	*Sciurus vulgaris*, *Myoxus* (*Glis*) *glis*	Debarking	Baiting

Table 1 - Continued.

Plant	Country	Species	Damage	Control
		EUROPE - continued		
Beech and sycamore	Britain	*S. carolinensis*, *S. vulgaris*	Bark-stripping	Trapping

Sources: Bernard, 1977; Dalmacio, 1974; Fiedler, 1985; Fiedler et al., 1982(a)(b); Hoque and Garrison, 1981; Hopf et al., 1976; Kuo and Liao, 1986; Muller and Macedo, 1980; Rodriguez and Herrera, 1984; Rana, 1983; Ruhm, 1966; Santini, L. A., 1986; Udagawa, 1968.