March 1992

CONTROL STRATEGIES TO REDUCE PREHARVEST RAT DAMAGE IN BANGLADESH

Parvin Sultana
Bangladesh Agricultural Research Institute

Michael M. Jaeger
U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Denver Wildlife Research Center

CONTROL STRATEGIES TO REDUCE PREHARVEST RAT DAMAGE IN BANGLADESH

PARVIN SULTANA, Bangladesh Agricultural Research Institute, Vertebrate Pest Section, Joydebpur, Bangladesh

MICHAEL M. JAEGER, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control, Denver Wildlife Research Center, P. O. Box 25266, DFC - Building 16, Denver, Colorado 80225-0266

ABSTRACT: The principal objective of this study was to determine when during the year the control of bandicoot rats would be most cost-effective under the agricultural conditions existing in Bangladesh. An annual cycle in the rise and fall of burrow density was found. This argues for a management strategy directed at reducing rat damage at a specific time period within the year as opposed to a strategy of continuous population reduction. A model predicting rat damage was developed based on monthly estimates of burrow densities in rice and wheat; and projected losses were compared among the four major cereal growing seasons (aman, boro, and aus rice, and wheat). The net benefit of control is predicted to be greatest during the aman rice season in both of the major agroecosystems occurring in Bangladesh.

Proc. 15th Vertebrate Pest Conf. (J. E. Borrecco & R. E. Marsh, Editors) Published at University of Calif., Davis. 1992

INTRODUCTION

Preharvest rat damage to rice and wheat is a chronic problem in Bangladesh. Losses are reported to be substantial (Posamentier and Alam 1980, Posamentier 1981, Poche et al. 1982, Ahmed et al. 1986). An intensive program of research into rodent control was begun in 1978 with the establishment of a vertebrate pest project funded by the United States Agency for International Development (USAID) and implemented by the Denver Wildlife Research Center (DWRC). As a result, considerable information existed on rodent problems and on the efficacy of a number of rodenticides (Poché et al. 1979, 1986, Brooks et al. 1985, Mian et al. 1987). What remained to be determined was when during the year control could be the most cost-effective under the agroecological conditions existing in Bangladesh.

The need to develop a selective strategy that focuses control at a particular time(s) of year assumes that (1) rat damage is a chronic problem; (2) long-term population reduction is impractical and, therefore, annual control is necessary; (3) rat numbers fluctuate seasonally due to predictable patterns of rainfall, flooding, crop production, or cover; and therefore, (4) crops grown at different times of the year are not equally vulnerable to rat damage. Research findings support these assumptions (e.g. Chakraborty 1975, Posamentier and Alam 1980, Pradham 1980, Fulk et al. 1981, Poché et al. 1982, Khokhar 1986, Srihari and Govinda Raj 1988). The objectives of this study were to (1) determine whether a predictable annual cycle in rat numbers exists, (2) determine when and where rats tend to concentrate, (3) estimate preharvest damage in rice and wheat, and (4) predict when control is the most cost-effective.

AGROECOLOGY

Seasonal Flooding

Bangladesh is situated in the delta formed by the confluence of the Brahmaputra, Ganges, and Meghna Rivers. Extensive flooding occurs annually from June to October coincident with the monsoon rains in south Asia Flooding usually peaks by mid-August when flood waters cover 1/3 to 1/2 of the country. In traditionally flooded areas, the villages become seasonal islands surrounded by water up to about 6 m in depth.

Cropping Seasons

Rice is grown throughout the year in Bangladesh in three seasons: aman (June-December), boro (December-June), and aus (April-August). Wheat is grown from December to March. The most important of these for national cereal production is aman rice (Fig. 1) which is planted with the onset of the monsoon rains (June-July). There are two types of aman rice: (1) deepwater-broadcasted for areas with a deep flood and (2) paddy-transplanted where shallow flooding occurs, representing about 16% and 84%, respectively, of the total aman production. Boro rice, second in overall production, is usually irrigated and gives the highest per hectare yield. Aus rice is planted with the early rains and has the lowest per hectare yield.

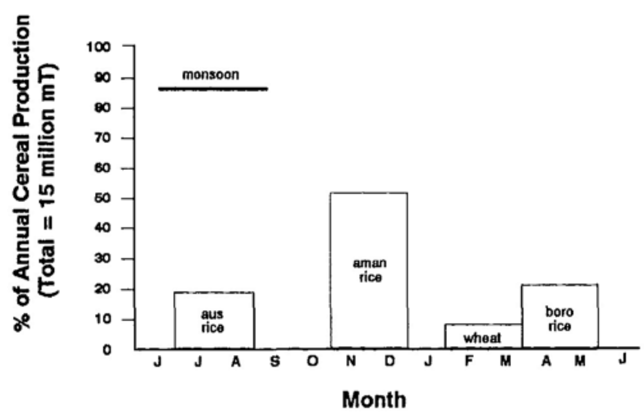

Figure 1. Seasonal timing of harvest of the major cereal crops of Bangladesh and the relative contribution of each to total annual grain production.

Rat Species

Bandicoot rats are the predominant rodent pests of ripening cereals throughout much of the Indian subcontinent including Bangladesh (Bindra and Sagar 1975, Greaves et al. 1975, Rejasekhoran and Dharmaraju 1975, Poché et al. 1982). Three species occur, the most common and destructive of which is the lesser bandicoot rat (*Bandicota bengalensis*). The greater bandicoot rat (*B. indica*) is more restricted in distri-

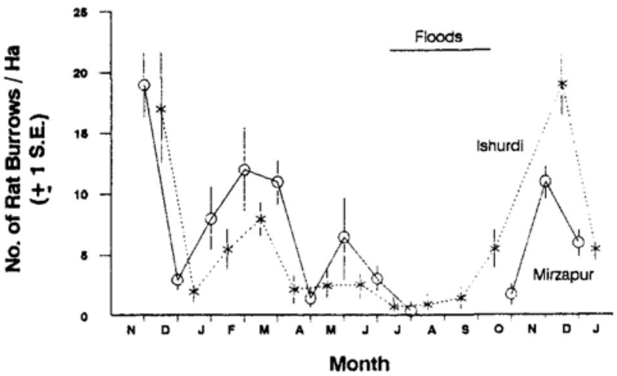

Figure 2. Annual pattern in the average monthly density of rat burrows in all fields at the Mirzapur and Ishurdi study sites in Bangladesh, November 1986-January 1988.

bution to seasonally flooded areas where deepwater rice is grown (Posamentier 1981, Ahmed et al. 1986). The short-tailed mole rat (*Nesokia indica*) has the most restricted distribution, being found only in relatively well-drained areas of northwestern Bangladesh (Poché et al. 1982). The roof rat (*Rattus rattus*) is also common, but it generally occurs in and around structures on which it can climb to seek shelter (Bindra and Sagar 1975, Mian et al. 1987). Trapping records from India suggest that *Rattus* spp. have been displaced by *B. bengalensis* except in areas near structures or near ship docks where *R. norvegicus* can still be found (Deoras 1966, Seal and Banerji 1966).

Bandicoot rats are fossorial and cache cut stems and panicles in their burrow systems. Burrows are usually found to be inhabited by a single adult rat (Sagar and Bindra 1971, Rejasekhoran and Dharmaraju 1975, Pochd et al. 1982); although Chakraborty (1975) reported finding burrows with from 1 to 4 adults. The burrows of *Bandicota* spp. are commonly found in the bunds or dikes demarcating individual fields. Active burrows are easily recognized by mounds of fresh tailings outside of the recently used tunnel openings. Active rat burrows were sampled in this study and used as a measure of the number of adult rats.

METHODS

Study Sites

The study was conducted at two field sites, near Mirzapur in Tangail District and near Ishurdi in Pabna District. Mirzapur is mainly a deepwater aman rice growing area, whereas Ishurdi is a transplanted aman rice area Pulses and mustard are commonly grown in both areas from January to March. Both areas have a high human density and are intensively cultivated.

Sampling

Field sites were sampled monthly from November 1986 to January 1988 to determine crop type and stage of development and the abundance of active rat burrow systems. At each site sampling was conducted along a 24-km transect of roadway which was divided into two strata, each of which was partitioned into 24 (1-km^2) blocks, 12 along each side of the road. The total area sampled at each site was, therefore, 4,800 ha. For the first 6 months of the study, 2 (1-km^2) blocks/stratum were randomly selected each month. In each of these blocks, 4 (1-ha) plots were randomly selected and sampled. Modifications in the sampling were then made so that from May 1987 until January 1988 4 (1-km^2) blocks/stratum were sampled each month. These blocks were randomly selected in May and the same blocks were sampled in each of the remaining months. Within each block 2 (1-ha) plots were randomly selected each month. A total of 16 (1-ha) plots was, therefore, sampled monthly at each site. Within each 1-ha plot, the number of fields was counted and the following information was recorded for each: area (m^2), crop type and stage of development, number of active rat burrow systems, and the presence of bunds and standing water. Means and variances were calculated in accordance with the two-stage sampling (Cochran 1983). The first stage was the 1-km^2 block; the second stage the 1-ha plot within the block.

Modeling Rat Damage

Projections of rat damage were made for each of the four cropping seasons to determine when during the year damage was greatest. A simple bioenergetic model was used to estimate damage for each site and cropping season. Damage was the product of the number of rat days in a crop and of the amount of crop that a rat damages per day. The number of rat days per hectare per crop per month was calculated as a function of a linear change in the average density of burrows over the 30-day sampling interval. In general, if burrows increased from A to C, then the total number of rat days over this time (T_R) would be

$$T_R = \int_0^{30} [A + \frac{(C-A)}{30} x] \; dx$$

For example, if the average number of burrows per hectare of wheat increased form 15 to 30, then

$$T_R = 15\,(15+30) \\ = 675 \text{ rat days}$$

T_R is converted to damage by multiplying by 75 g, a constant which represented what we determined as the average daily damage of an adult *B. bengalensis* (consumption plus hoarding). Damage was, therefore, 50.6 kg/ha for this example. If wheat represented 10% of the area sampled at a particular site (4,800 ha), then the overall projected loss of wheat for that site is 24.3 mT.

Four assumptions were made to construct this model. First, any change in rat numbers over the 30 day sampling interval was linear. This seemed reasonable, given that any pair of rats could produce only a single generation during this period. The second assumption was that each active burrow system represented a single adult rat. This was validated in two ways: (1) releasing 5 groups of *B. bengalensis* (♂♂, ♀♀, ♂♀, ♂♂♀, ♀♀♂) each into a separate outdoor enclosure (11 x 5.5 m) and counting the number of burrows that resulted after two weeks then repeating the procedure with new animals each month for a year, and (2) excavating active burrow systems in the field and counting the number of adults found in each. All rats released in the enclosures that were either not removed by predators or otherwise escaped (n = 114) dug burrows. A total of 305 burrows of *B. bengalensis* were excavated, and a single adult was found in all but one. Likewise, in 58 burrows in which *B. indica* were found, all contained a single adult. The third assumption was that adult rats removed

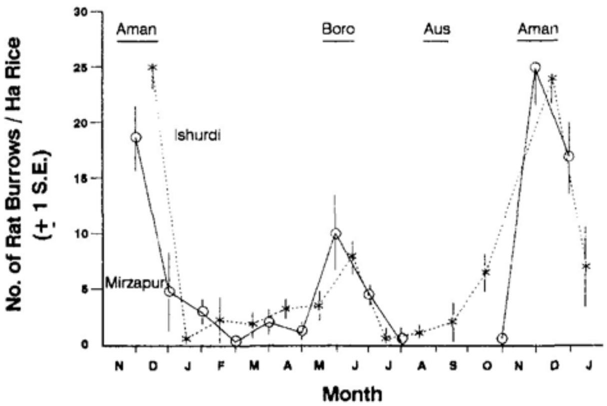

Figure 3. Annual pattern in the average monthly density of rat burrows in rice fields at the Mirzapur and Ishurdi study sites in Bangladesh, November 1986-January 1988.

an average of 75 g of rice seed (dry wgt) per day. This figure was determined by averaging the number of rice panicles clipped and removed per day by *B. bengalensis* over a two week period (x = 48.9 panicles/day/rat) and multiplying this amount by the average dry weight of rice seed in a panicle (1.5 g). This test was done in the outdoor enclosures and repeated monthly throughout one year as part of the previously described burrowing experiment. This estimate for individual damage was similar to Parrack's (1969) estimate of 67 g/day of seed removed by *B. bengalensis,* but may underestimate damage by the larger *B. indica.* The fourth assumption was that the two *Bandicota* spp. were the principal pests of ripening grain and that the impact of *Nesokia indica* was negligible.

RESULTS

Temporal Distribution of Burrows

The seasonal pattern of fluctuation in the monthly density of rat burrow systems showed a similar trend at both sites (Fig. 2). An overall peak of 15-20 burrows/ha occurred in November-December coincident with the timing of the aman rice harvest. The 1987 peak at Mirzapur was lower than that of 1986, probably the result of the extensive flooding in this area during the preceding August and September. A secondary peak occurred in March coincident with the wheat harvest, followed by a tertiary peak in May-June coincident with the boro harvest. The seasonal low of less than one burrow/ha occurred in July and August. Sampling could not be done at Mirzapur during August and September because of flooded roads; it was assumed that burrow numbers remained low. Overall burrow density increased sharply at both sites coincident with maturation of the aman crop.

Spatial Distribution of Burrows

Burrows tended to be concentrated in those fields where ripening cereals and cover (bunds bordering dense vegetation) were available. Burrow densities within fields of aman and boro rice and wheat rose sharply during the month(s) preceding harvest. Fields were small at both Mirzapur and Ishurdi, averaging 0.12 and 0.19 ha respectively. Within the 1-ha sampling units, fields usually comprised a mosaic of crop types and stages of maturity that probably facilitated the rapid concentration of rats into preferred fields.

The highest concentration of rat burrows in rice was associated with the aman harvest, where densities ranged from 18-26 burrows/ha of rice in the 2 years sampled (Fig. 3). Densities in boro rice reached 7 and 10 burrows/ha of rice at Ishurdi and Mirzapur, respectively. There was no noticeable peak in aus rice, which was flooded at the time of harvest. The highest density was 57 burrows/ha of wheat at Mirzapur, about double that in wheat at Ishurdi. Burrow density in the subsequent boro rice crop was also lower at Ishurdi.

Burrows were most concentrated in wheat because relatively little wheat was cultivated, representing only about 11 % of the area sampled at both sites. This compared to about 60% for aman, 20-30% for boro, and 35-42% for intercropped aus/aman rice. Approximately 90% of all rat burrows found in March were in wheat. Rats shifted to wheat fields from nearby pulse or mustard fields when these were harvested, mostly in February (Fig. 4). Pulses and mustard provided the first vegetative cover for rats following the aman harvest.

Projected Rat Damage by Season

The seasonal pattern in projected rat damage was roughly similar at both sites with die greatest losses in aman rice, followed by wheat, boro rice, and aus rice (Fig. 5). Aman rice loss in the predominantly transplanted rice growing site at Ishurdi was estimated at 131.6 mT or 71.4% of the total annual loss projected for that site compared with 73.6 mT or 47.0% of the total annual loss projected for the predominantly broadcast, deepwater rice at Mirzapur. In wheat, the projected loss was 62.9 mT at Mirzapur and 26.1 mT at Ishurdi representing 40.2% and 14.2%, respectively, of the total annual loss at each site. Damage to boro rice was 10.1% and 11.0% of the total annual loss at Mirzapur and Ishurdi, respectively, compared with 2.7% and 3.4%, respectively, for aus rice. Overall annual damage to rice and wheat by burrowing rats was projected at 184.2 mT for Ishurdi, or 2.3% of the expected yield, compared to 156.5 mT, or 1.9% of the expected yield, at Mirzapur.

Costs and Benefits of Control

Monetary losses due to rat damage were substantially greater in aman rice than in any of the 3 other cereal seasons (Fig. 6). This is because coarse rice is more valuable on the local market (U.S. $286/mT) than wheat (U.S. 183/mT; source USAID/Dhaka, November 1988). The net benefits of control during the different cropping seasons are compared in Figure 7. For each season, projections were made for both sites, two treatment times (1 vs. 2 months prior to harvest), and three levels of effectiveness (25, 50, and 75% reduction in rat days/ha from the onset of treatment). Two additional assumptions were made for this model: (1) all rat burrows were treated once at a cost of $0.09/burrow; and (2) there was no carry-over effect from one crop season to another (e.g., aman rice to wheat). This model predicts that the overall net benefit of control (for each 4,800-ha site) is greatest during the aman rice season in both agroecosystems. It also indicates that the net benefit of control could be negligible (e.g., during the month preceding the aus harvest) even when the control effort was effective in reducing the number of rat days.

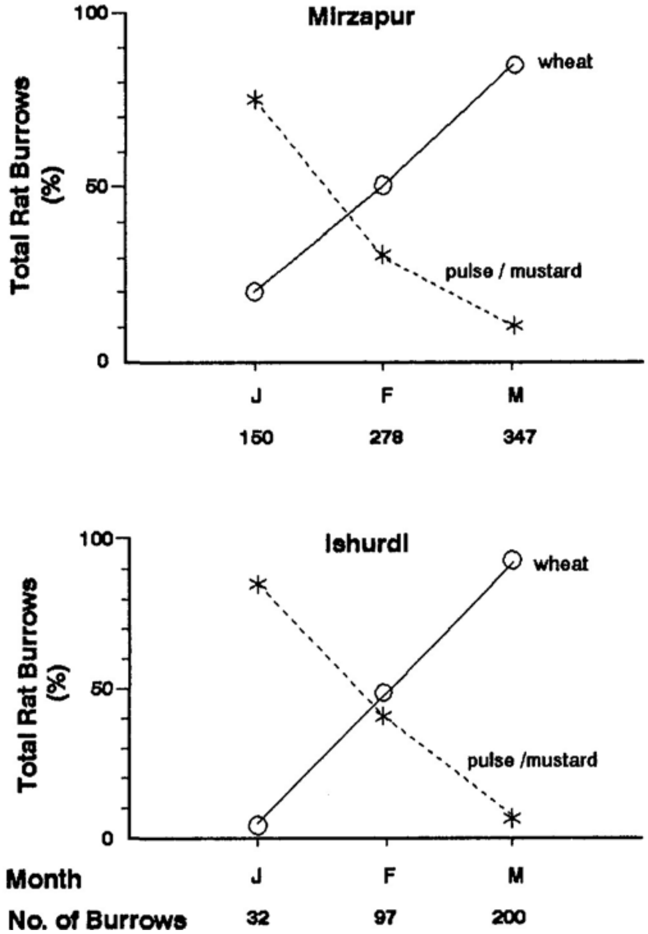

Figure 4. Relative abundances of active rat burrow systems in wheat and pulse/mustard fields at Mirzapur and Ishurdi, Bangladesh, during 1987.

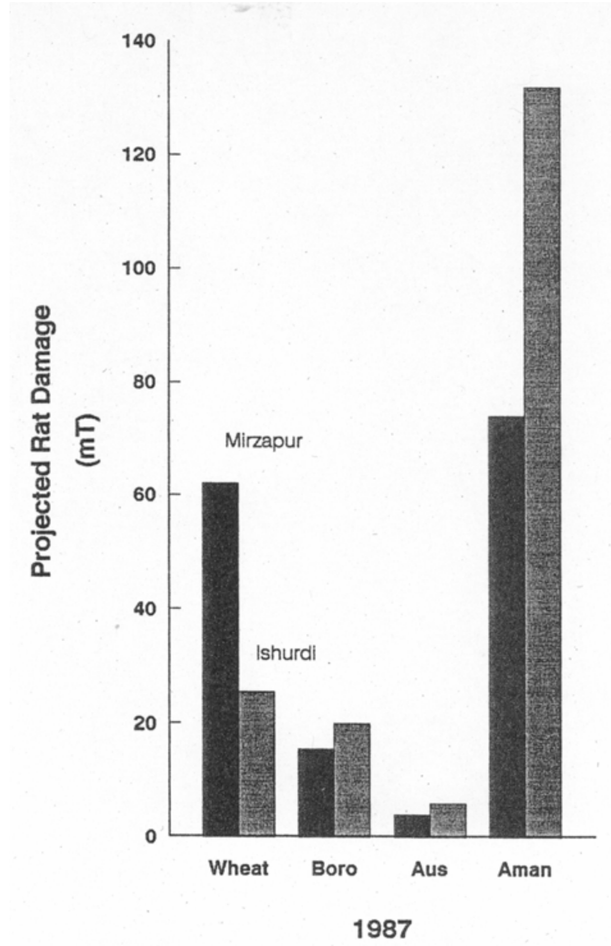

Figure 5. Projected rat damage in each of the four major cereal growing seasons at Mirzapur and Ishurdi, Bangladesh, during 1987.

DISCUSSION

Seasonal Fluctuation in Rat Numbers

The results presented here suggest a regular annual cycle in the numbers of bandicoot rats in the rice/wheat growing areas of Bangladesh. Populations are highest in November-December, coincident with the main rain-fed crop (aman rice), and lowest from the end of the dry-season (May-June) until recession of flood waters in September and October. The secondary and tertiary peaks in burrow numbers which coincide with the wheat and boro rice harvests, respectively, may not accurately reflect changes in rat numbers, but may result partly from the plowing over of burrow openings following the aman rice and pulse/wheat harvests. Rats may remain underground in their burrows following these major harvests that remove cover, and subsist on caches of grain, mollusks, insects, and water available in the deeper tunnels of their burrows (Ahmed et al. 1985). Therefore, there may be a more steady decline in the numbers of bandicoot rats through the dry-season than is depicted in Figure 2.

This general pattern was consistent with the findings of others describing seasonal trends in the numbers of *B. bengalensis* in field situations (Chakraborty 1975, Fulk et al. 1981). Reproduction was greatest from September to November and lowest from May to July in paddy fields near Banglore, India (Srihari and Govinda Raj 1988), where it was presumed that breeding was triggered by the maturing grain crop. This explanation may partly account for the secondary and tertiary peaks in burrow numbers found in Bangladesh. However, it does not account for the greater burrow density associated with aman rice compared to boro or aus rice.

Rats are important prey for a variety of mammals, birds, and reptiles in Bangladesh. Rodents, including *Bandicota* spp., were found to be the principal food items of jackals throughout the year in the 2 study sites sampled in the present study (Sultana and Jaeger 1989). Rat mortality may increase relative to natality as the dry season progresses and both vegetative cover and hours of darkness per night decrease. Furthermore, *B. bengalensis* may be more vulnerable to predators during the dry season when they are concentrated in relatively small areas such as wheat (Sultana and Jaeger 1989).

Monsoon flooding is also likely to be an important factor contributing to the mortality of burrowing rodents as suggested for *B. bengalensis* in the delta of the Indus in Pakistan by Wagle (1927) and Fulk et al. (1981). The severe flooding in Bangladesh in early September 1988 resulted in an estimated 53% reduction in the density of rat burrow systems from mid-August to late September at one 4,800-ha study site (Sultana unpubl.). Similarly, the relatively low peak in the density of burrows at Mirzapur in November-December

1987 (Fig. 2) was probably the result of the unusually high and prolonged floods in the area at that time.

Seasonal Changes in Rat Distribution

Bandicoots are known to abandon burrows and emigrate several hundred meters or more to a new site in response to changes in food availability, cover, floodwater, or population pressure (Frantz 1973, 1984, Fulk et al. 1979, 1981, Poché et al. 1986). It has been generally assumed that emigration accounts for the seasonal disappearance of rat burrows from fields and that rats move to higher ground around housing clusters and road embankments with the onset of flooding. This interpretation is consistent with farmers' reports that rats are especially numerous in their houses during the floods. Two lines of evidence, however, suggest that such movement cannot account for the difference between annual highs and lows in burrow density in fields. First, the general decline in burrow density occurs throughout the dry season, with low levels being reached before onset of the rains. Second, while burrow density increased in fanners' houses at the time of flooding, overall burrow density remained low (Sultana unpubl.).

It has been suggested that as the flood recedes rats, principally *B. indica,* leave the high ground and move out onto a mat of floating vegetation, mainly the stems of deepwater rice (Mian 1982). This implies that burrow counts may not be a valid measure of rat numbers during the time of flood recession. However, burrow fumigation in a deepwater rice growing area during the time of flood recession resulted in a significantly lower burrow density at harvest compared with a control treatment (Sultana unpubl.). If many rats were living only on the floating vegetation, then burrow control would have been expected to have little, or no, impact on post-flood burrow density.

Magnitude of Preharvest Damage

Based on this model the magnitude of annual rat damage was similar in the projections from both of the sites sampled in this study despite differences between them for individual crops. It is therefore reasonable to assume that annual nationwide damage also ranges from 1-3% of the expected yield. At 1988 production levels (Fig. 1), this damage represents 150,000-450,000 mT per annum. Projected losses in individual crops were in general agreement with some of the prior estimates of preharvest rat damage in Bangladesh (Posamentier and Alan 1980, Posamentier 1981) but lower than others for wheat (Poché et al. 1982, Brooks et al. 1985, Sultana et al. 1982). Damage is not uniformly distributed, particularly in wheat, where rats tend to be more concentrated where there is less area of wheat planted. Localized damage may therefore be relatively high, but it is unlikely that nationwide damage could average as high as the 12.1% reported by Poché et al. (1982). Areas with relatively little wheat and relatively high damage may inflate the estimates of loss if they are not weighted in proportion to their representation in the total area of wheat sampled.

Implications for a National Management Strategy to Control Rodent Damage

We have concluded that selective annual control directed at reducing rat damage would be a better management strategy than long-term population reduction. The sharp increase in overall burrow density from the annual low of less than one

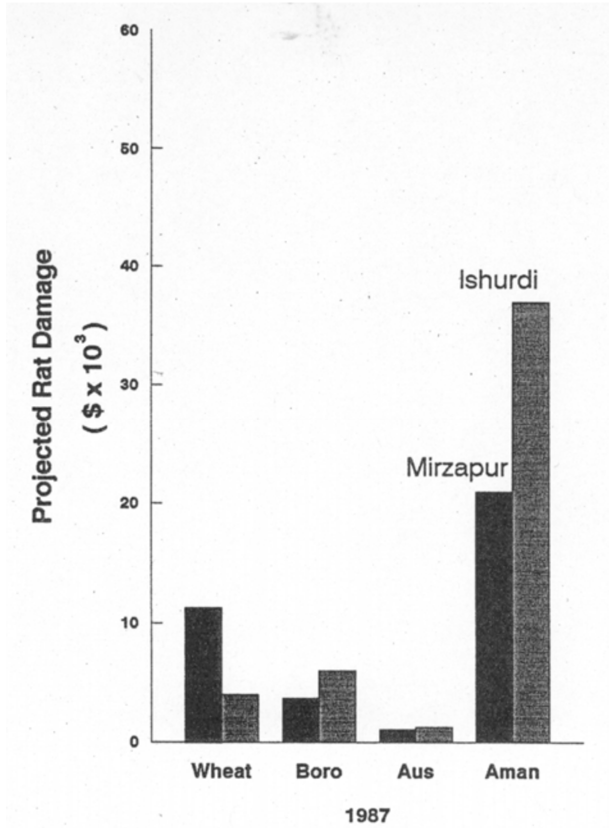

Figure 6. Value of projected rat damage in each of the four major cereal growing seasons at Mirzapur and Ishurdi, Bangladesh, during 1987.

burrow/ha in July-August to the annual high of about 18 burrows/ha in November-December suggests that a long-term population reduction would be impractical to maintain. Furthermore, seasonal control takes advantage of the naturally occurring decline in rat numbers each year and of the temporal proximity of this low to the principal period of crop damage.

Our rat damage model predicts that control of bandicoot rats could be most cost-effective in September or early October when the rat population begins to increase coincident with the maturation of the aman rice crop. The optimal time for control may vary with location depending on the occurrence of flooding and maturation of the crop. Regardless, burrow control should follow the peak flood and precede the flowering/booting stage of the crop (Poché et al. 1981). Within this timeframe, early treatment would be more cost-effective because there would be fewer burrows to treat. In general, control efforts should be undertaken earlier in transplanted aman rice than in broadcast-deepwater aman rice. The cost-effectiveness of control in aman rice could be further enhanced if there is a carry-over effect to subsequent wheat and boro rice crops. Evidence suggests that burrow densities could be significantly reduced in both crops with effective control in aman rice (Sultana 1990).

Coordinated rodent control efforts by all of the farmers in an area and directed at rodent burrow systems would also seem important for control to be cost-effective. Fields are small and usually in various stages of development which allows rats to readily move among them and concentrate in

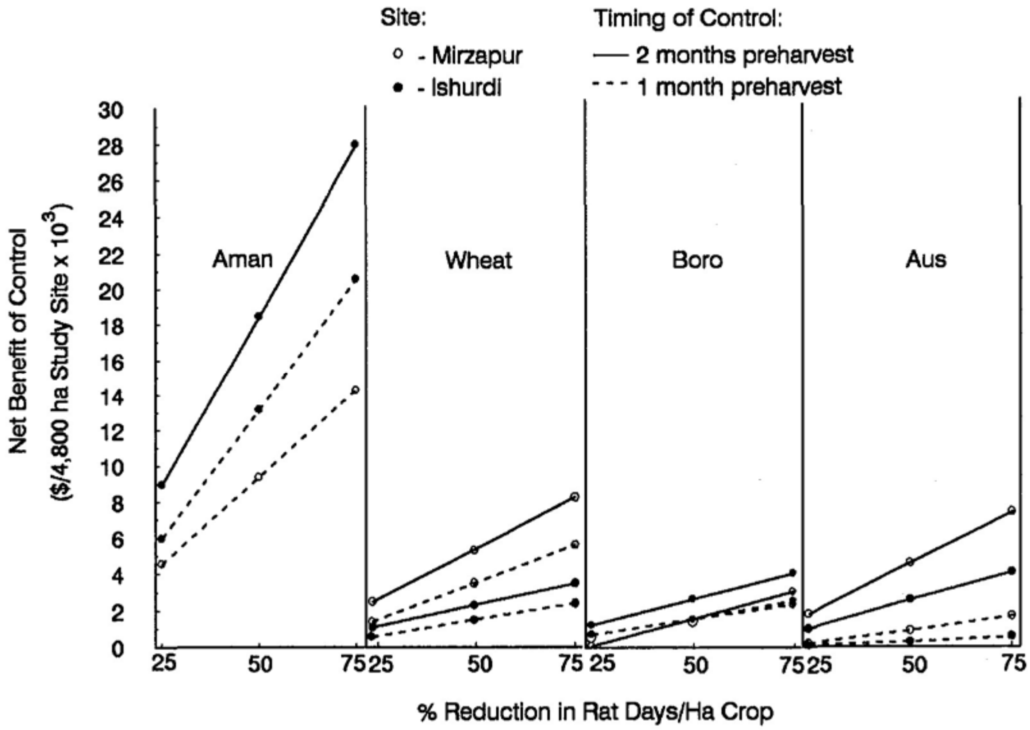

Figure 7. Comparison of the net benefits of control in each of the four major cereal growing seasons at Mirzapur and Ishurdi, Bangladesh, during 1987. Projections include two treatment times (1 vs. 2 months prior to harvest), and three levels of effectiveness (25, 50, and 75% reduction in rat days/ha of crop from the onset of treatment).

preferred situations. Farmers who wait to conduct control in only their own fields risk an influx of rats at the time their crop is most vulnerable to damage, when rat numbers are highest and when reinvasion is most likely. Subsequent field tests have demonstrated that the farmers in an area can successfully implement the control strategy proposed here (Sultana 1990).

ACKNOWLEDGMENTS

We thank J. Brooks, R. Bruggers, M. Fall, L. Fiedler, D. Otis, R. Poché, R. Reidinger, and M. Tobin for their comments on an earlier draft. We are especially grateful to D. Otis for his help with the sampling procedure and modeling. P. Groninger, M. Tudor, and M. Cameron prepared the computer graphics; and M. Jaeger typed the original manuscript.

Funds were provided by USAID under the project "Agricultural Research II Vertebrate Pest Management Component, PASA IBD-0051-P-IF-2252-05."

LITERATURE CITED

AHMED, M. S., M. E. HAQUE, and J. E. BROOKS. 1985. Alternative foods of bandicoot rats in deepwater rice areas of Bangladesh. Int. Rice Res. Newsl. 10:31.

AHMED, M. S., M. Y. MAN, M. E. HAQUE, and J. E. BROOKS. 1986. Bandicoot rat damage in deepwater rice fields. Int. Rice Res. Newsl. 11:25.

BINDRA, O. S., and P. SAGAR. 1975. A review of studies on the ecology, biology, damage and control of field rats and field mice in the Punjab. Pages 82-88 In: Proc. All India Rodent Seminar (K. Krishnamurthy, G. C. Chaturvedi, and I. Prakash, eds.). Ahmedabad, India. 377 pp.

BROOKS, J. E., P. SULTANA, and R. M. POCHE. 1985. Damage by *Bandicota bengalensis* to growing wheat in Bangladesh and methods of control. Acta Zool. Fenn. 173:135-137.

CHAKRABORTY, S. 1975. Field observation on the biology and ecology of the lesser bandicoot-rat, *Bandicota bengalensis* (Gray) in West Bengal. Pages 102-112 In: Proc. All India Rodent Seminar (K. Krishnamurthy, G. C. Chaturvedi, and I. Prakash, eds.). Ahmedabad, India. 377 pp.

COCHRAN, W. G. 1963. Sampling Techniques (Second Edition). John Wiley and Sons, New York.

DEORAS, P. J. 1966. Significance of probable change in rat population in Bombay. Pages 58-68 In: Indian Rodent Symposium. Calcutta, India. 314 pp.

FRANTZ, S. C. 1973. Behavioural ecology of the lesser bandicoot rat, *Bandicota bengalensis* (Gray) in Calcutta. Ph.D. Dissertation, The Johns Hopkins University, Baltimore, Maryland. 233 pp.

FRANTZ, S. C. 1984. Home range of the lesser bandicoot *rat, Bandicota bengalensis* (Gray) in Calcutta, India. Acta Zool. Fenn. 171:297-299.

FULK, G. W., S. B. LATHIYA, and A. R. KHOKHAR. 1981. Rice field rats of the lower Sind; abundance, reproduction and diet. J. Zool. (Lond.) 193:371-390.

FULK, G. W., A. C. SMIET, and A. R. KHOKHAR. 1979. Movements of *Bandicota bengalensis* (Gray 1873) and *Tatera indica* (Hardwicke 1807) as revealed by radiotelemetry. J. Bombay Nat. Hist. Soc. 76:457-462.

GREAVES, J. H., G. W. FULK, and A. KHAN. 1975. Preliminary investigations of the rice-rat problem in Lower Sind. Pages 24-28 In: Proc. All India Rodent Seminar (K. Krishnamurthy, G. C. Chaturvedi, and I. Prakash, eds.). Ahmedabad, India. 377 pp.

KHOKHAR, A. R. 1986. Field ecology of *Bandicota bengalensis.* Pak. J. Zool. 18:61-65.

MAN, M. Y., 1982. Ecology and control of sympatric rodents on islands adjacent to deepwater rice in Bangladesh. M.Sc. Thesis, University of the Philippines, Los Banos, Philippines, 111 pp.

MIAN, M. Y., M. S. AHMED, and J. E. BROOKS. 1987. Small mammals and stored food losses in farm households in Bangladesh. Crop Prot. 6:200-203.

PARRACK, D. W. 1969. A note on the loss of food to the lesser bandicoot rat, *Bandicota bengalensis.* Curr. Sci. 38:93-94.

POCHÉ, R. M., M. E. HAQUE, M. Y. MIAN, P. SULTANA, and M. A. KARIM. 1981. Rice yield reduction by simulated rat damage in Bangladesh. Trap. Pest Manage. 27:242-246.

POCHÉ, R. M., M. Y. MIAN, M. E. HAQUE, and P. SULTANA. 1982. Rodent damage and burrowing characteristics in Bangladesh wheat fields. J. Wildl. Manage. 46:139-147.

POCHE, R. M., M. Y. MAN, R. STERNER, M. E. HAQUE, and P. SULTANA. 1986. Rodent movement in wheat fields. Mammalia 50:165-172.

POCHÉ, R. M., P. SULTANA, M. Y. MIAN, and M. E. HAQUE. 1979. Studies with zinc phosphide on *Bandicota bengalensis* (Gray) and *Rattus rattus* (Linnaeus) in Bangladesh. Bangladesh J. Zool. 7:117-123.

POSAMENTIER, H. 1981. Observations on three species of rodents in deepwater rice in Bangladesh. Z. Angew. Zool. 68:155-167.

POSAMENTIER, H., and S. ALAM. 1980. Rodent damage and control in wheat in Bangladesh during the 1980 season. Bangladesh J. Zool. 8:99-101.

PRADHAN, M. S. 1980. Sex ratio and breeding season of field rats from Goregaon and Malad. Indian J. Ecol. 7:29-37.

REJASEKHARAN, M. R., and E. DHARMARAJU. 1975. Studies of field rodents in Andhra Pradesh. Pages 54-55 In: Proc. All India Rodent Seminar (K. Krishnamurthy, G. C. Chaturvedi, and I. Prakash, eds.). Ahmedabad, India. 377 pp.

SAGAR, P. and O. S. BINDRA. 1971. A note on the lesser bandicoot, *Bandicota bengalensis* (Gray) in the Punjab. Pages 55-56 In: Proceedings and Recommendations of the International Symposium on Biomass and Control of Rodents (S. L. Perti, Y. C. Wai and C. P. Srivastava, eds.). Kanpur, India

SEAL, S. C. and R. N. BANERJI. 1966. Changing patterns of rodent population in Calcutta and Howrah. Pages 69-83 In: Indian Rodent Symposium. Calcutta, India. 314 pp.

SRIHARI, K. and G. GOVINDA RAJ. 1988. Effective period for control of *Bandicota bengalensis* in paddy fields. Trap. Pest Manage. 34:141-146.

SULTANA, P. 1990. Developing a strategy for extending rodent control technology to the Bangladeshi fanner. Unpubl. report. Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

SULTANA, P., and M. M. JAEGER. 1989. The impact of jackal predation on preharvest rat damage in Bangladesh. Technical Report No. 35, Vertebrate Pest Section, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

SULTANA, P., J. E. BROOKS, and R. M. POCHE. 1982. Methods for assessing rat damage to growing wheat in Bangladesh with examples of applications. Pages 231-238 In: Vertebrate Pest Control and Management Materials: Fourth Symposium (D. E. Kaukeinen, ed.). American Society for Testing and Materials Special Technical Publication 817. 315 pp.

WAGLE, P. V. 1927. The rice rats of the lower Sind and their control. J. Bombay Nat. Hist. Soc. 32:330-338.