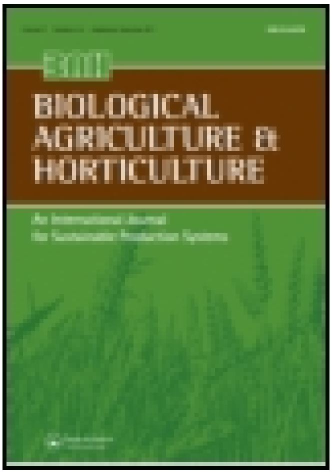

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Rodent outbreak in relation to bamboo flowering in north-eastern region of India

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Rodent outbreaks have been recorded in the north-eastern hill region of India since time immemorial. This study was carried out in Arunachal Pradesh where rodent outbreaks are associated with *Dendrocalamus hamiltonii*, *Dendrocalamus strictus*, *Bambusa tulda*, *Bambusa balcoa* and *Schizostachyum arunachalensis*. Four species of rodents are reported in the flowering area of which *Rattus rattus* is predominant and causes greatest damage to many crops. The greatest damage recorded in rice ranged from 12.9% to 15.4% in the bamboo flowering year, whereas it was 5.3% to 5.8% in the non-flowering year. Higher levels of damage were also observed in maize, pineapple, cabbage, French bean, potato, tomato and tapioca in bamboo flowering affected area than in other areas. Live burrows count, trap index and percent damage revealed that in bamboo flowering areas, the rodent population was significantly increased. The comparison of nutrient content of bamboo seeds and other food materials suggested that higher carbohydrate content of the bamboo seeds triggered the active behaviour of rodents. Damage was caused only to those crops which are a very good source of carbohydrate. The cumulative effects of rainfall, flowering season, hunting of predatory animals or birds and geographical barriers might be responsible for the outbreak of rodents. The study also explains why every flowering season does not result in a rodent outbreak of the same severity.

Keywords: bamboo flowering; rat; rodent damage; rodent outbreak

Introduction

Rodents are a major group, representing 42% of mammals, with more than 2700 species worldwide. In India, the north-eastern hill (NEH) region, comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, is located between 21°35′ and 29°22′ north and 85°41′ and 97°60′ east, and has a total area of 272,315 km^2. These states, except Assam, have more than 50% forest cover, which is much above the national average. The economy of the NEH region is primarily agriculture based with the majority of the people still practising jhum or shifting cultivation by burning trees and other plantation on hill slopes along with wetland rice cultivation (WRC) at lower altitude and on plains. Natural vegetation, primarily bamboo

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forests, surrounds the crop fields and provides the most favourable habitat for rodents in the NEH region of India (Figure 1).

Rodents are a serious threat in residential premises and stores. Vigorous flowering and seeding in certain species of bamboos are believed to cause severe rodent outbreaks in the region in certain years, resulting in famine. Bamboo flowering interval is genetically triggered and ranges from less than 10 years to more than 120 years (Janzen 1976). In Mizoram, periodic famines were associated with the flowering and fruiting cycle of *Melocana baccifera* (local name mautak) and *Bambusa tulda* (local name rawthing). The flowering, fruiting and dying of mautak is called mautam whereas that of rawthing is called thingtam. The gap between mautam and thingtam is found to be almost regular, being 30 years from thingtam to mautam and 18 years from mautam to thingtam. Famines which occurred in 1864, 1910–1912 and 1958–1959 were associated with mautam, and those in 1880–1884, 1928–1929 and 1976–1977 were associated with thingtam. The recent famine in Mizoram during 2007–2008 was associated with mautam. The next expected thingtam and mautam will be in 2025–2026 and 2055–2056, respectively (Directorate of Agriculture 2009).

As a conservative estimate, the forest area with bamboos in India is about 9.57 Mha (12.8%) of the total forest area of 75 Mha. Major bamboo growing states of the country are Arunachal Pradesh (19,790 km^2), Assam (10,000 km^2), Manipur (2500 km^2), Tripura (750 km^2) and West Bengal (164 km^2). There are 124 indigenous and exotic species under 23 genera found naturally (Biswas 1988). Clump-forming bamboo constitutes over 67% of the total growing stock, of which *Dendrocalamus strictus*, *Bambusa bambos*, *Dendrocalamus hamiltonii*, *B. tulda* and *Bambusa pallid* occupy 45%, 13%, 7%, 5% and 4%, respectively. All other species put together are 6%. *Melocanna baccifera*, a non-clump forming bamboo, accounts for 20% of the growing stock and is found in the north-eastern states (Haridasan et al. 1987). It is not clear that bamboo flowering, rainfall and nutritional factor of bamboo seeds are linked with rodent outbreak. This investigation was carried out to study the effect of rodent pests in predominant cropping systems, to study the effect of bamboo flowering on rodent activity and to compare the nutritional value of different rodent foods including bamboo seeds.

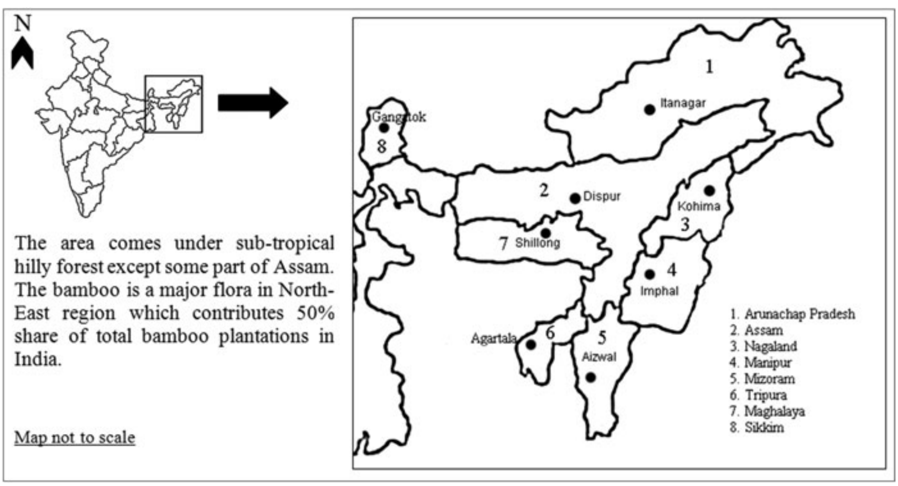

Figure 1. North-eastern region of India where sporadic and mass bamboo flowering occurs at frequent intervals. Numbers denote the name of states in this region.

Materials and methods

Surveillance of rodent pests in predominant cropping systems

A survey was conducted in 2009–2010 and 2010–2011 in the following districts of Arunachal Pradesh; east Siang, west Siang, upper Siang, lower Siang and Papumpare. Among them, east Siang district experienced sporadic bamboo flowering during 2009. Five species of bamboo, *D. strictus, D. hamiltonii, Dendrocalamus gigaenteus, B. tulda* and *Schizostachyum arunachalensis* are predominant in these areas. Of these, *D. hamiltonii* flowered in April–May 2009. Selected plots of WRC, jhum rice, maize, tapioca, potato, pineapple, tomato, cabbage, French bean and cauliflower were studied in this investigation. Average spread of bamboo patches is around 5 m diameter each with a distance of 10–50 m between. The distance between the bamboo patches and crop fields is usually 50–150 m excluding the jhum rice plots, where it is very close to the bamboo patches with an average distance of 10–20 m. The trap index (number of animals per 100 traps per night), live burrow count (number per hectare), extent of damage and reproductive status of the species were recorded in the surveyed area according to the method given by Aplin et al. (2003). The analysis was done by using randomized block design and *t*-test for significance of difference of means based on arcsine-transformed value (Panse & Sukhatme 1967; Gomez & Gomez 1984).

Effect of bamboo flowering on rodent activity in rice ecosystem

Monitoring for bamboo flowering *vis-à-vis* rodent problem was carried out in Koyu village of east Siang District, where flowering of *D. hamiltonii* and *S. arunachalensis* were observed in 2009. The monthly data on rodent populations and damage in rice crop were taken in the year 2010 for comparison with the data of 2009. The same observations were also taken in four other villages Yagrum, Korang, Sido and Tene at monthly intervals for comparison with the data obtained from Koyu to find out the difference in rodent outbreak during bamboo flowering.

Nutritional value of bamboo seeds and other staple foods

Grains of rice, maize, pearl millet and wheat, tubers of colocasia, tapioca and potato, fruits of *Castonopsis indica*, and seeds of *D. hamiltonii* and *S. arunachalensis* were collected from the study areas to compare the nutritional value of bamboo seeds and other staple foods. Seed samples were crushed to form fine powder, whereas tuber and fruit samples were ground to prepare paste. Total protein was estimated by the Bradford method (Bradford 1976) while total carbohydrate and non-reducing sugar were determined by the anthrone method (Hodge & Hofreiter 1962). Reducing sugar estimation was carried out using Nelson–Somogyi procedure (Somogyi 1952). Total lipid and starch were determined according to Sawhney and Randhir (2000).

Results

Surveillance of rodent pests in predominant cropping systems

Rattus rattus was the predominant species and caused greatest damage in different crops (Table 1). Greatest numbers of live burrows (49.38 and 21.10 ha^{-1}) were reported in WRC during 2009 and 2010, respectively, followed by jhum rice 27.83 and 17.17, respectively. Among the horticultural crops, the greatest number of live burrows was recorded in tapioca (29.22 and 15.79 ha^{-1}), whereas the fewest were reported in cauliflower (0.33 and 0.68 ha^{-1}) during 2009 and 2010, respectively (Table 1). The highest trap index was

Table 1. Surveillance of *R. rattus* in predominant cropping systems in Arunachal Pradesh.

	Live burrows (ha^{-1})		Trap index		Damage (%)	
Crop	2009	2010	2009	2010	2009	2010
Rice (WRC)	49.38	21.10	20.50	10.95	9.9	5.3
Rice (jhum)	27.83	17.17	23.29	14.28	21.1	6.4
Maize	13.33	05.37	7.78	4.55	9.9	1.7
Tapioca	29.22	15.79	7.78	3.00	10.7	6.9
Potato	6.25	05.39	10.00	2.92	0.1	0.2
Pineapple	14.26	18.49	15.64	11.17	18.6	12.6
Tomato	–	1.79	10.00	3.11	2.9	0.9
Cabbage	2.33	2.98	3.88	2.83	1.7	0.9
French bean	2.11	3.99	4.64	3.80	2.1	1.1
Cauliflower	0.33	0.68	–	–	–	–

Note: Data represent the mean of three replications per field of five villages.

recorded in jhum rice cultivation (23.29 and 14.28) and the lowest in cabbage (3.88 and 2.83) during 2009 and 2010, respectively. The trap index decreased in 2010, the non-flowering year.

The greatest damage was reported in jhum rice (21.1%) followed by pineapple (18.6%), tapioca (10.7%), maize (9.9%) and WRC (9.9%) during 2009 in which bamboo flowering occurred (Table 1). During 2010, the damage decreased due to the absence of bamboo flowering. During this year the greatest damage was recorded in pineapple (12.6%) followed by tapioca (6.9%), jhum rice (6.4%) and WRC (5.3%). No trap index and damage were recorded in cauliflower (Table 1).

Four species of rodents that were found to cause losses in crops in this region were recorded during the survey. *R. rattus* and *Bandicota bengalensis* were found in all cropping systems. *Mus cookiinagarum* caused damage only in rice crops near the forest area. *Hylopetes alboniger*, commonly known as particoloured flying squirrel, which inhabits dense forest and orchards and feeds on fruits and seeds of trees (Molur et al. 2005), was found to cause damage in pineapple fields. Many adult rodents trapped were in optimal breeding conditions, i.e. pregnant and lactating (Table 2).

The data on trap index and percent damage were also recorded in east Siang and west Siang districts of Arunachal Pradesh (north-east India) during the years 2009 and 2010 in predominant cropping systems (Table 3). The trap index ranged from 1.00 to 26.46 in various cropping systems of both the districts in the year 2009, whereas in the year 2010, the

Table 2. Reproductive status of *R. rattus* in different areas of Arunachal Pradesh during trapping.

Crop	Sex ratio (M:F)	Unpregnant (%)	Pregnant (%)	Lactating (%)
WRC	1:0.95	74	19	7
Jhum rice	1:0.94	74	19	68
Maize	1:0.80	63	38	–
Tapioca	1:0.87	73	18	9
Potato	1:0.75	57	29	14
Pineapple	1:1.10	69	20	11
Tomato	1:0.58	67	33	–
Cabbage	1:0.64	73	9	18
French bean	1:0.83	75	8	17

Table 3. Trap index and percent damage of rodents in two districts of Arunachal Pradesh.

	Trap index		Damage (%)		
Crop	2009	2010	2009	2010	Rodent species found[a]
East Siang District					
Rice	21.89	12.61	15.5	5.8	*Bb, Rr, Mc*
Maize	8.25	4.55	9.9	1.7	*Bb*
Pineapple	13.29	11.17	15.6	12.6	*Bb, Rr, Ha*
Cabbage	4.24	2.83	2.2	0.9	*Bb*
Cauliflower	0	0	0	0	
French bean	5.76	3.80	3.0	1.1	*Rr*
Potato	6.67	4.58	1.9	1.0	*Bb, Rr*
Tomato	10.00	7.69	2.9	1.1	*Bb, Rr*
Tapioca	7.77	5.23	10.7	7.5	*Bb, Rr*
West Siang District					
Rice	26.46	14.13	12.9	5.3	*Bb, Rr, Mc*
Maize	7.54	4.25	3.4	1.2	*Bb, Rr*
Pine apple	11.12	12.58	16.4	18.5	*Bb, Ha*
Cabbage	1.00	0.64	1.0	0.8	*Bb*
French bean	6.22	3.84	2.7	1.2	*Rr*
Potato	2.48	1.26	0.7	0.3	*Bb, Rr*
Tomato	4.96	2.15	1.2	0.7	*Bb*
Tapioca	2.48	0.88	0.5	0.3	*Rr*

[a]*Ha*, *Hylopetes alboniger*; *Bb*, *Bandicota bengalensis*; *Mc*, *Mus cookiinagarum*; *Rr*, *Rattus rattus.*

range was 0.88–14.13. The greatest damage recorded in rice crop ranged from 12.9 to 15.5% in the bamboo flowering year 2009, whereas it was 5.3–5.8% in non-flowering year 2010. In cauliflower, only a few live burrows were recorded but no trap index and damage were reported.

Effect of bamboo flowering on rodent activity in rice ecosystem

Five villages Koyu, Tene, Yagrum, Korang and Sido were selected for recording the observations in east Siang district in 2009 and 2010. Two types of rice cultivation, jhum and WRC, were observed with three replications in each village. A high trap index was recorded in Koyu village during both years in both rice cultivation systems (Table 4), and this was significantly higher than in the other villages except for Tene village where it was at par with Koyu village in jhum rice during 2010. This effect may have occurred because Tene village is near Koyu village and the rodent population might have migrated from the flowering area to nearby crop fields. The lowest trap index was found in Yagrum and Korang villages which were at par with each other and situated far from the bamboo flowering area.

Damage levels of 26.2% and 9.7% were observed in jhum rice in Koyu in 2009 and 2010, respectively, significantly higher than in the villages Yagrum and Korang in 2009, and higher than in Yagrum, Korang and Sido in 2010, which were situated away from the flowering area. A similar trend was observed in WRC where damage was recorded in Koyu village and was at par with Tene in 2009 and with Tene and Sido in 2010 but significantly higher than in the other villages. The least damage was observed in Yagrum in 2010 in both rice cultivation methods, but in 2009, there was no significant difference in damage percent in jhum rice between Yagrum and Sido, and in WRC among Yagrum, Korang, Sido and Tene villages. Yagrum is in a relatively flat area. Significant difference

Table 4. Rodent activity in bamboo flowering areas in Arunachal Pradesh during 2009 and 2010.

Rice	Village	Trap index		Reduction in trap index from 2009 to 2010 (%)	Damage (%)		Reduction in damage from 2009 to 2010 (%)
		2009	2010		2009	2010	
Jhum rice	Yagrum	18.33 c*	10.83 b	24	16.5 c	2.6 c	62
	Korang	20.83 c	5.83 c	49	21.5 b	5.1 b	53
	Sido	19.17 c	15.00 b	12	18.7 bc	6.9 ab	40
	Tene	25.00 c	15.83 ab	22	22.5 ab	8.4 ab	40
	Koyu†	32.50 a	21.67 a	20	26.2 a	9.6 a	41
Wet land rice (WRC)	Yagrum	10.00 c	6.67 c	19	9.1 b	1.5 c	60
	Korang	18.33 b	6.67 c	41	5.6 b	4.9 b	7
	Sido	23.33 b	10.00 bc	35	7.8 b	6.9 ab	6
	Tene	20.83 b	12.50 b	24	10.3 ab	8.0 a	12
	Koyu†	30.00 a	19.17 a	22	13.5 a	9.5 a	17

Notes: Data represent the mean of three replications per villages in a crop season.
*Means for the same year and rice system not followed by the same letter differ significantly at $p < 0.05$. Significance of difference of means based on arcsine-transformed values.
†Village in which bamboo flowering occurred during year 2009.

was observed in trap index between the years 2009 and 2010. Reduction in trap index in the non-flowering year 2010 ranged from 12% to 49% in the villages. Crop damage observed in 2009 was also significantly higher with reduction in damage from 2009 to 2010 ranging from 6% in wet land rice to 62% in jhum rice (Table 4).

Nutritional value of bamboo seeds and other staple foods

The nutritional value in terms of protein, non-reducing sugar, reducing sugar, total carbohydrate, total lipid and starch content of *D. hamiltonii*, *S. arunachalensis*, local varieties of rice and other staple foods was studied. The highest protein content was found in *C. indica* (12.11 g 100 g^{-1}) followed by that in wheat (11.20 g 100 g^{-1}), pearl millet (10.35 g 100 g^{-1}) and maize (10.30 g 100 g^{-1}). Protein content of *D. hamiltonii* (3.19 g 100 g^{-1}) and *S. arunachalensis* (6.24 g 100 g^{-1}) was found to be more than that of the tuber crops. However, protein content of *D. hamiltonii* is less than that of other staple foods in the study (Table 5). Non-reducing sugar, reducing sugar and total carbohydrate obtained from *D. hamiltonii*, *S. arunachalensis* and *C. indica* were found to be higher than those from cereal grains, which are major sources of rodent food. High value of total carbohydrate was recorded in *S. arunachalensis* (92.70 g 100 g^{-1}) and *C. indica* (80.92 g 100 g^{-1}). Total lipid content of cereal grains and bamboo seeds was found to be higher than that in the tuber crops. *S. arunachalensis* was found to have poor starch reserve (17.6 g 100 g^{-1}); similarly, *D. hamiltonii* also exhibited low starch content (43.7 g 100 g^{-1}). *S. arunachalensis* and *C. indica* were found to be rich sources of energy with 424 and 425 kcal 100 g^{-1}, respectively.

Discussion

Significantly higher trap index and percent damage were observed in 2009 in which bamboo flowering occurred than in 2010 when flowering did not occur. Jaksic and Lima

Table 5. Nutritional value of bamboo seeds, cereal grains and other staple foods.

Food	Protein (g 100 g^{-1})	Non-reducing sugar (g 100 g^{-1})	Reducing sugar (g 100 g^{-1})	Total carbohydrate (g 100 g^{-1})	Total lipid (g 100 g^{-1})	Starch (g 100 g^{-1})	Energy (kcal 100 g^{-1})
D. hamiltonii	3.19	57.27	12.98	71.70	1.60	43.7	314
S. arunachalensis	6.24	42.75	53.95	92.70	3.12	17.6	424
Boro rice	6.10	42.84	4.28	47.60	3.05	67.6	242
Shillong rice	5.10	33.01	7.18	41.00	2.25	41.8	205
Deku rice	5.34	39.43	5.01	45.00	2.67	47.3	225
Amkel rice	6.08	34.33	5.10	40.00	3.04	71.6	212
Itanagar rice	6.70	42.08	9.82	53.00	3.35	72.6	269
Maize	10.30	53.30	8.91	63.20	5.30	62.2	342
Pearl millet	10.35	39.53	20.49	62.30	5.18	68.4	337
Colocasia	0.56	60.54	14.18	76.30	0.30	83.7	310
Tapioca	0.72	59.75	13.63	74.90	0.39	60.6	306
Potato	1.74	52.80	15.21	69.70	0.87	81.2	294
Wheat	11.20	62.65	11.20	75.10	1.26	52.2	357
Castonopsis indica (fruit)	12.11	45.89	31.52	80.92	5.87	69.2	425

(2003) reported that rodent irruption is associated not only with bamboo flowering, but also with rainfall peaks and is geographically interspersed over South America. The relationship between rodent activity and percent damage in pineapple and rice crop was not the same. The rodent population remained constant in pineapple in all the areas, whereas it was unstable or fluctuated in the rice crop. Thus, this investigation reflects that rice and maize crops were more prone to rodent attack than pineapple at the time of rodent outbreak and bamboo flowering. These findings support those of Leung et al. (1999) that potato is a good indicator of low densities of rice rodent population. Tapioca was gnawed by the rodents even in low populations surrounding rice crop. No trap index and damage in cauliflower crop were recorded even in the rodent outbreak season, revealing that it may be a non-preferred food of the rodents.

Valid scientific reasons for the sudden outbreak of rodents during flowering of bamboo are still not understood. It might be due to sudden changes in the entire ecosystem of the bamboo forest, which helps rodents in switching over from *k* to *r* patterns of faster breeding, higher than the carrying capacity of the forest resulting in mass migration of native rodents to surrounding jhum and WRC crop fields, causing large-scale devastation of standing crop. Ecologically, rodent outbreaks represent explosive increases in population abundance or density of rodents during a relatively short period. Because these irruptions are closely associated with exogenous factors such as rainfall or bamboo flowering, they appear to be the result of a population increase closely related to changes in the environment, with population dynamics being governed by simple regulatory structures. As a consequence, populations may be disrupted under the effects of strong changes in food levels (Jaksic 2001). Although it is not scientifically confirmed, it is assumed that the rodents eat the bamboo seed, using the abundant food resources to increase their breeding potential and expand their population. It has also been purported that bamboo seed may contain potential oestrogenic compounds that stimulate reproduction, which again is not confirmed. A scientific analysis of bamboo seed by the Department of Agriculture, Government of Mizoram, India, revealed that a compound that triggers the breeding potential of rodents is not present in bamboo seed (Directorate of Agriculture 2009). Some people consider that bamboo seeds are highly nutritious and increase the fertility of rats, but there is no clear evidence for this myth. The comparison of nutrients contents of bamboo fruits or seeds and other food items shows no indication that bamboo seed is more nutritious than other foods. This supports the study by Lalnunmawia (2009). The chemical analysis of seeds of the bamboo, *B. arundinacea*, showed them to be comparable to wheat in their protein content but to rice in their protein quality (Rao et al. 1955; Mitra & Nayak 1972). These bamboo seeds produced in 1969 were consumed by local people without any biological changes in Orissa, India (Mitra & Nayak 1972). However, high carbohydrate and protein content of the bamboo seeds might be related to the active behaviour of rodents as damage was caused mainly to those crops that are a very good source of carbohydrate. Abundant supply of energy-rich bamboo seeds and other foods might be related to increased possibility of litter survival in flowering-affected area. An increased survival rate of juveniles would lead to significant production of rodents in successive generations.

Nag (1999), John and Nadgauda (2002), Douangboupha et al. (2003) and Jaksic and Lima (2003) observed that linkages between bamboo flowering and rodent outbreak have not been proven, and the causes of rat outbreak were mere speculation. However, this study indicates that the rodent outbreak might be related to bamboo flowering. Sporadic bamboo flowering occurs at frequent intervals in Arunachal Pradesh, and the rodent population increases in the flowering area compared with other areas. Lima et al. (1999a, 1999b) and Holmgren et al. (2001) linked rodent population outbreaks to variation in rainfall, with unusually high rainfall leading to rat outbreak due to increased vegetative matter on which rodents feed. However, in this study, there was no relationship between rainfall pattern and rodent outbreak observed. Detailed study of the correlation between different agro-climatic factors for longer duration and rodent eruption is required.

The indiscriminate hunting of predatory animals such as cat, fox, wolf and predatory birds may be a secondary factor affecting rodent populations. The local tribes hunt wild animals as a hobby; they also celebrate a hunting festival in the first week of March. Geographical barriers may be another cause for irruption. This hilly area is geographically isolated from other hills by streams as the region has high rainfall. In this situation, the increasing rodent population cannot migrate to another area and ultimately the population reaches carrying capacity. Weather, geographical distribution, food and predation may be responsible for outbreak in North America (Sage et al. 2007; Witmer & Proulx 2010). This hypothesis can explain why all flowering seasons do not give rodent outbreaks of the same severity. The variation in the timing and abundance of seed produced in an area can dictate the severity of the rodent outbreak, e.g. earlier season seed production gives the rodent outbreak longer to expand, with higher amount of the seed also causing larger scale outbreaks. In Arunachal Pradesh, bamboo flowering occurs continuously over quite small patches. Nearby hills may not flower in the same year, leading to sporadic flowering outbreak that proceeds over 2–3 years. Many of the adult rodents trapped in this study were in optimal breeding condition. In other words, abundant food in the form of bamboo seed means that rodents become very healthy and large, allowing them to produce large, frequent litters of young rats. As the seed is exhausted by the predation and germination, the rats immigrate to farms in the vicinity and damage the standing crops, thus bringing about famine as an aftermath of bamboo flowering. This hypothesis is supported by Kitzberger et al. (2007). This also indicates that the exodus of rodents occurs at the end of, and not during, seeding. These relatively rare flowering events cause widespread ecosystem changes that have not been properly studied and analysed within India, Bangladesh, Myanmar and elsewhere in the world.

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