The widely held traditional belief that bamboo flowering can lead to rodent outbreaks and famine is nowhere more deeply embedded in wider cultural values than in Mizoram, the southernmost of the northeast Indian states. This mountainous region supports extensive bamboo forests dominated by species of bamboo with semelparous masting reproduction and their schedule of highly synchronized reproduction is said to underpin a cycle of rodent outbreaks and famine, with events spaced approximately every two decades. The largest-scale events are associated with the flowering of Melocanna baccifera, an ecologically aggressive bamboo species that covers more than 26,000 km² of the northeast Indian states, extending also into adjoining areas of the Chin Hills of Myanmar and the Chittagong Hill Tracts of Bangladesh. This species has a lifespan of approximately 48 years, reproduces with a high degree of synchrony, and is a prodigious producer of fruits—up to 83.6 tons per hectare. Details of two previous Melocanna masting events, in 1910-12 and in 1958-60, are available from colonial sources; both events were followed by rodent outbreaks leading to extensive crop destruction and famine, with significant human mortality. A Melocanna masting event occurred on schedule in Mizoram in 2006-08. The unfolding of this event was carefully monitored by agronomists and forest ecologists. Although a detailed study of rodent population dynamics was not possible, attempts were made through repeated observations at several sites to understand the fundamental elements of outbreak ecology. We conclude that provision during the course of the dry season of large quantities of nutritious bamboo fruits stimulates the early onset of breeding in Rattus rattus and other bamboo forest-dwelling rats, thus causing a population increase several months earlier than during nonmasting years. The final stages of bamboo fruit production in July to August coincide with the first availability of maturing maize in jhum fields, and crop damage is observed from this time onward. Where rapid and severe damage is incurred at the ripening stage of rice, this is inflicted largely by large numbers of immature rats, thereby creating a characteristic but unfamiliar (to farmers) pattern of damage. We postulate that the severity of damage may be determined, at least in part, by the timing of first fruit production and associated rat breeding relative to the local cropping calendar. This hypothesis can be tested in the context of masting events involving other bamboo species and, if confirmed, it holds promise for developing predictive models that may alleviate much hardship associated with bamboo-related rodent outbreaks in several parts of the world.

Keywords: rodent outbreaks, bamboo mast, mautam, Mizoram, jhum
Seeing is believing

Perhaps some things just have to be seen to be believed. Throughout Asia, farming peoples believe that the episodic mass flowering (“masting”) of bamboo causes rodent outbreaks and famine (Janzen 1976), and similar beliefs are also espoused among subsistence farmers in South America (Jaksic and Lima 2003). Many rural people in Asia claim to have seen it, quite often more than once in their lifetime. Until recently, however, no scientist has claimed to have been witness to either this chain of natural events or its aftermath. Strangely, although these beliefs are given a high level of credence and they have a high profile in the Indian literature on forest ecology and rodent management (Ghosh 1980, Lianzela 1997, John and Nadgauda 2002, Rao 2004), outside of this context the phenomenon has usually been reported with varying degrees of skepticism (Soderstrom and Calderón 1979, Singleton and Petch 1994 citing W. Roder, Schiller et al 1999) or, more often, simply ignored. Rather telling, recent reviews of the impacts of resource pulses on natural systems (Yang et al 2008, 2010) contain scant reference to what might be some of the most dramatic and large-scale examples of this ecological phenomenon.

To some extent, the skepticism or aversion of western scientists toward this issue has been well founded. As will be explored further below, many of the claimed attributes of these rodent outbreaks fall into the realm of the improbable if not the mythological. As with many myths, there may be embedded grains of truth in the notion that bamboo flowering causes an explosion of rats. But exactly what are the plausible elements in this particular case? From a scientific perspective, the principal issue has been dearth of what might be called “hard” evidence, that is, documentation using scientific methods by “qualified” scientists. In the Asian context, the one field study of rodent populations during a bamboo flowering event (Chauhan 1981, 2003, Chauhan and Saxena 1985) failed to produce evidence of large increases in rodent numbers or of extensive population movements of the kind often mentioned in the “anecdotal” accounts. Similarly, a study of historical records of rodent outbreaks in Laos (Douangboupha et al 2003) failed to yield a compelling case for bamboo flowering as a cause of the outbreaks, although this was certainly not discounted. In the South American context, previous analyses of these phenomena (e.g., Jaksic and Lima 2003) relied entirely on second-hand sources and it was only very recently that an ecological study of a bamboo flowering-associated *ratada* was completed (Sage et al 2007).

In the Asian context, one bamboo masting event surpasses all others in its scale and claimed impacts—this is *mautam*, the masting (and subsequent mass mortality—*tam* means death) of a particularly widespread bamboo called *Mau* by the regional peoples, *muli* by the wider Indian community, and *Melocanna baccifera* (henceforth, *Melocanna*) by the international scientific community. *Melocanna* bamboo forests cover huge areas of northeastern India and surrounding areas of Bangladesh, Myanmar, and Nepal, with a total area in India alone probably in excess of 26,615 km² (Rao 2004, Jeeva et al 2009). From historical records, it is believed that masting of *Mau* bamboo occurred across northeastern India in 1815, 1863, 1911, and 1959, suggesting an approximately 50-year flowering cycle (Nag 1999, Shibata 2009). Ac-
cordingly, the scientific community eagerly awaited mautam in the first decade of the 21st century. Here at last would be an opportunity to see bamboo flowering on a grand scale, and to obtain that elusive “proof” or, to return to a more scientific framework, to test some alternative hypotheses. Inhabitants of the northeast Indian states as well as adjoining parts of Myanmar and Bangladesh also awaited mautam, though with a genuine mixture of curiosity and dread.

But, before progressing to the special story of Mizoram, it is worthwhile making a brief side trip into the remarkable world of bamboo.

About bamboo

In many traditional Asian cultures, bamboo rivals rice as the single most important product of nature (Kurz 1876, McClure 1966). Not only is it the principal or sole building construction material, it is also essential for transportation; the manufacture of tools, furniture, paper, and clothing; and, in the form of bamboo shoots, it is an important food item. All of these uses continue today, but with the addition of new uses that take advantage of the remarkable natural fiber strength of bamboo. For the great majority of Asian peoples, bamboo is thus central to life and culture, and most people are familiar with its essential biological and ecological properties. In contrast, the majority of western scientists have little or no first-hand knowledge of bamboo other than as an ornamental garden plant. To begin thinking about possible ecological links between bamboo and rats, those of us who have not grown up with bamboo might begin by humbly asking, “What could be special about bamboo?”

In botanical classification, bamboos comprise the subfamily Bambusoideae, which is a specialized offshoot of the grass family Poaceae (Das et al 2008). More than 1,400 species of bamboo, classified into around 90 genera, are distributed throughout the tropical to temperate regions of all continents (Ohrnberger 1999, Wong 2004). The highest diversity of bamboos is found in China, but India and China together have the largest areas of bamboo, which often forms extensive, near-monotypic stands (Bystriaková et al 2003). Like most other grasses, bamboo species tend to be fast growing and to grow best under well-lit conditions. As a result, they tend to be particularly common in successional rather than climax plant communities, growing either in small gaps created in forest by tree-fall or landslides, or in larger clearings created by flooding, natural wildfires, or human activities, including agriculture. In Asia, they are a major component of early to mid-stages in forest regeneration following slash-and-burn or shifting cultivation (Lianzela 1997, Tawnenga et al 1996).

Bamboos vary enormously in growth form. They include both herbaceous (soft and grass-like) and woody (hard and tree-like) forms, and can grow either from a simple root stock (monopodial) or from a root stock that includes specialized roots called rhizomes that allow the plant to expand below-ground (sympodial), with culms arising from nodes along the rhizomes (McClure 1966, Sodestrom and Calderón 1979). Sympodial bamboos can be further classified as “clump-forming,” where the rhizomes are short and the culms are closely grouped, or “spreading,” where the rhizomes grow outward and the culms are more regularly spaced.
The reproductive biology of bamboos is remarkably varied and highly pertinent to the theme of rodent outbreaks (John et al 1994, Shanmughavel and Francis 2001). Three contrasting reproductive modes have evolved among the bamboos: a sporadic mode, a synchronized “masting” mode, and a semelparous masting mode. Under sporadic reproduction, an individual bamboo plant flowers and sets seed multiple times through its lifespan, usually on an annual basis, and with either no particular seasonal pattern or, more commonly, a general seasonality determined by annual climatic cycles. Synchronized masting bamboos also tend to flower and set seed multiple times through their individual lifespan but, in these species, reproductive activity is generally not annual. Instead, it appears to be triggered by dramatic environmental events such as fire or drought, and these often occur only on multiannual time scales. This reproductive mode presumably allows the bamboo to place maximum reproductive effort into the windows of greatest opportunity—the creation of large clearings in which a higher proportion of bamboo seed might germinate and flourish (Keeley and Bond 1999).

Most synchronized masting bamboos are also semelparous. Bamboos of this group reproduce only once in their lifespan and they do so in a highly synchronized manner—large numbers of plants flower more or less at the same time, and then all die shortly thereafter, bringing about a complete generational replacement of the species at a local to regional scale. The lifespan of semelparous bamboos varies between species and ranges from a decade or so up to more than a century (Janzen 1976). Many species of semelparous masting bamboos show local synchrony of flowering but vary considerably in the timing of flowering across larger geographic areas. In a smaller number of species, the synchronicity extends to all populations of a species, such that the vast majority of individual plants will flower and die within an interval of only a few years (e.g., Franklin 2004, Shibata 2009). Reproductive activity in semelparous masting bamboos is controlled by an internal “clock” that signals to the plants when it is time to flower, set seed, and die, irrespective of external environmental cues. The strongest evidence for this remarkable biological property comes from numerous cases of transplanted semelparous bamboos flowering simultaneously even when grown in entirely different climates (Janzen 1976, Shibata 2009). Flowering in plants is a complicated process that is controlled by interactions among multiple gene products, including some that seem to regulate timing through dose-rate mechanisms (Mouradov et al 2002). The molecular mechanism of synchronized flowering in bamboos is only now starting to be understood (Tian et al 2005).

Semelparous masting bamboos can also undergo sporadic flowering but this does not result in the death of the plant and fruit generated in this way tends to be infertile (John et al 1994, Shanmughavel and Francis 2001). Within the main period of flowering activity, a few plants typically flower one or two years earlier and later than the main bulk of the plant, perhaps reflecting genetic diversity within local populations (Watanabe et al 1982, Franklin 2004). Widely distributed species often have spatial variation in the principal flowering time, so that the main flowering activity seems to move around or even across the landscape in a directional “flowering wave.”
There is considerable debate over the evolutionary advantages of semelparity in bamboos, with two principal competing hypotheses—predator satiation (e.g., Janzen 1976) and the fire hypothesis (e.g., Keeley and Bond 1999, but see Saha and Howe 2001). Whatever its origins, semelparity is most prevalent among bamboos growing in tropical areas that experience strongly seasonal climates under monsoonal influence. Not surprisingly, India has the highest proportion of semelparous masting bamboos (70 out of 72 species, Gadgil and Prasad 1984, Campbell 1985), and eight of these species are regarded as strictly synchronous (Kelly 1994).

The flowering process itself is also unusual in bamboos. In most species, every culm can potentially develop into a flowering shoot (John et al 1994). When this begins to happen, the leaves turn brown and gradually all drop off, and the culm develops flowering spikelets at nodes and apices, and sometimes also along flowering side branches. A flowering culm can eventually have all of its originally leafy components transformed into flowering shoots (Wong 2004: 35). In some species, flowering shoots can also develop directly from rhizomes. The reproductive process of Melocanna baccifera was described in detail by Banik (1994, 1998) and Ramanayake and Weerawardene (2003).

Bamboo fruit (technically a “caryopsis”) contains a single propagule (John et al 1994). In most species, the fruit is dry and not much larger than a grain of rice or wheat (Chatterji 1960, Wong 2004). In a few genera, the fruit is fleshy and much larger, resembling a pear or avocado fruit in size and shape. In some of the fleshy-fruited bamboos, the seed can germinate either after falling or while still attached to the parent plant (Kurz 1876, Stapf 1904). Bamboo fruit typically shows prompt high germination rates and a marked decline in seed viability within a matter of months (Janzen 1976, Banik 1994). However, several temperate-zone bamboos appear to display seed dormancy (Matumura and Nakajima 1981, Taylor and Qin 1988). The nutritional value of bamboo fruits includes typically high starch and protein contents (Iwata and Nakajima 1942, Mitra and Nayak 1972). Melocanna fruit submitted by Rokhuma (1988: 131-132) for chemical analysis to the Forest Research Institute, Dehradun, yielded values of 50.3% starch, 11.6% protein, 3.0% ash, and 0.2% fats.

Mizoram—regional context and environment

**Geographic setting**

Mizoram is one of the six states that make up northeastern India—a region wedged between Bangladesh to the west and Myanmar to the east, and only narrowly connected with the rest of India (called the “mainland” by Mizo people) via a narrow bridge between Assam and West Bengal states (Fig. 1). Mizoram has a total land area of 21,087 km² and is bordered to the east by Myanmar, to the west by Bangladesh, to the northwest by Tripura State, to the northeast by Manipur State, and to the north by Assam. It supports a population (last counted in 2003) in excess of 922,000 people living in 22 towns and 700 villages, giving an overall population density of 44 persons per km² (Government of Mizoram 2003). However, more than half of the present population lives in urban centers, with more than 250,000 people located in the state with a population density in excess of 500 persons per km².
capital Aizawl. A period of rapid population expansion through the 1980s and 1990s included large numbers of immigrants from Assam and the “mainland,” with the result that the population today has very mixed origin (Hazarika 1995).

Mizoram sits astride a geological collision or Suture Zone between the Indian landmass and the Indochinese region. This accounts for its remarkably rugged topography, which comprises numerous predominantly north-south-trending ranges, separated by narrow, deep valleys. The average height of the ranges is about 900 m, with the highest peak (Phawngpui—Blue Mountain) rising to 2,210 m. Mizoram has a mild
climate with a winter temperature range from 11 to 21 °C and a summer range of 20 to 29 °C. The entire area is under the influence of the South Asian monsoon, which brings heavy rain from May to September. The average annual rainfall, measured at Aizawl, is 208 cm (Government of Mizoram 2003).

Flat land is a rare commodity in Mizoram, and most human settlements as well as agricultural fields are emplaced on ridges and steep slopes. This characteristic landscape and pattern of human settlement extend into bordering parts of both Bangladesh (the Chittagong Hill Tracts) and Myanmar (the Chin Hills), and also typify many other parts of northeastern India.

**Land cover and Mizo agriculture**

More than 87% of the land area of Mizoram is covered with forest (Government of Mizoram 2003, Nose 2009). The proportion of forested land is highest in the northern and eastern parts of Mizoram, and less in the south. Most of the remaining land area is occupied by active gardens, plantations, and early stages of regeneration after gardening.

According to Champion and Seth (1968), the natural vegetation of Mizoram is tropical evergreen and semi-evergreen forest at low altitudes, and subtropical to montane subtropical forest at higher elevations. Bamboo is present in all forest types but usually only conspicuous along streams and in areas recovering from natural disturbance (e.g., landslides, tree-fall). Much of the original forest that remains today is protected in wildlife and forestry reserves.

Outside of forest reserves, a large proportion of the forest cover is dominated by bamboo species. One species, *Melocanna baccifera*, dominates all others; in 2009, almost pure stands of this one species covered an area of 9,210 km² (Nose 2009). The extensive bamboo forests in northeastern India are regarded as an anthropogenic (i.e., created by people) forest community, a direct by-product of *jhum* agriculture (Lianzela 1997, Rao and Ramakishnan 1998, also see below).

**Agricultural systems in Mizoram**

In 2002-03, a total area of 158,397 ha was under cultivation in Mizoram, almost all of it farmed using the traditional slash-and-burn method, known locally as *jhum* agriculture (Government of Mizoram 2003). Irrigated fields, mainly located in Kolasib District bordering Assam State, amounted to 12,612 ha. A further 247,069 ha were land at various stages of fallow. Fruit orchards and vegetable fields occupied a further 57,858 ha and 40,970 ha, respectively.

The principal crop produced in 2002-03 was rice (109,205 tons), followed by maize (14,879 tons), sugarcane (7,443 tons), oilseed (5,285 tons), and pulses (4,986 tons). Just over 61% of total rice production came from *jhum* fields farmed using traditional methods. Total rice production in 2002-03 was estimated at only 40.8% of the state’s self-sufficiency target (Government of Mizoram 2003).

The *jhum* cropping cycle in Mizoram (Fig. 2) is typical of slash-and-burn practices followed across all of northeastern India (Ramakrishnan 1992) and into upland regions of Indochina (Roder 2001). The cropping activity is intimately linked to the
Fig. 2. The Mizo *jhum* cropping cycle and its relationship to the annual distribution of rainfall. Rainfall values are shown as means and standard deviations, based on the combined records for Aizawl for 1981-2006.

monsoonal cycle, with planting timed to coincide with the onset of rains in late April to early May. To be ready for this event, fields are cleared of standing vegetation in February to March, with debris typically burned in early April. The majority of *jhum* fields support a variety of intermingled crops—typically including maize, mustard seed, and numerous vegetables. Early-maturing maize is generally ready for harvesting in June, with late maize and rice usually harvested sometime between early September and early October. Farmers grow numerous rice varieties but two of the more popular are known locally as *tai* (a sticky rice) and *buhpui*. Both are slow-maturing varieties that are planted at the same time in mid- to late April and harvested in early to mid-September and mid-November to early December, respectively.

In the past, areas of primary or advanced secondary forest were selected for clearing. Today, areas of forest are typically reserved and *jhum* fields are far more likely to be created through cutting of *Melocanna* bamboo forest. Field preparation therefore involves the cutting and burning of the culms, leaving the underground rhizome mat to send up new shoots into the cleared space. Regeneration of the *Melocanna* bamboo creates a heavy burden of weeding in most *jhum* fields. *Jhum* fields are typically surrounded on one or more sides by dense stands of *Melocanna* forest.

Official state records begin in 1974 and show that the total land area under crop production has increased by only around 10% since that time (Government of Mizoram 2003). However, analysis of satellite photographs, the earliest dating from 1972, shows large-scale loss of dense forest cover across Mizoram during the 1980s (Lele and Joshi 2009), coinciding with the period of most rapid population growth. By 1999, much of these areas were again covered in dense forest, with large areas dominated by *Melocanna* forest.
Mizoram rodent ecology

The rodent fauna of Mizoram was documented taxonomically from early collections by Nath (1952) and Ghosh (1965), with more recent assessments by Agrawal (1980) and the present authors. The dominant rodent species in all human-associated habitats is the black rat (Rattus rattus), a remarkable opportunist that may have originated as a disturbance specialist in the subtropical forests of South to Southeast Asia but today occupies virtually every major ecological region of the world (Aplin et al 2003). Two critical features that seem to underpin the success of this species (or rather group of species, as it will very likely be taxonomically subdivided in the near future) are its relatively high reproductive potential, its apparent capacity to breed whenever food is available in sufficient quantity and quality, and its propensity to shift its diet depending on availability. Rattus rattus in its various forms is the dominant rat of agricultural environments as well as village habitats throughout much of Asia (Aplin et al 2004).

Other species found mainly in villages and fields across Mizoram are the Himalayan rat (R. nitidus), the Polynesian rat (R. exulans), and the house mouse (Mus musculus). Rats found exclusively in fields and forest habitats include several species of white-toothed rats (Berlymnys spp.), spiny rats (Niviventer fulvescens), several species of mice (Mus cervicolor and M. cookii), and bamboo mice (Chiropodomys gliroides). Bamboo rats (Cannomys badius) are also found in fields and forests. The forest ecosystem also supports other small mammals, including tree shrews (Tupaia sp.) and a variety of squirrels (species of Callosciurus and Dremomys). Overall, the small mammal community of Mizoram resembles closely that of the uplands of Myanmar and Laos (Aplin et al 2007), with only minor differences in species composition.

Information on the ecology of Mizoram rodents derives from the ecological studies of Chauhan (1981, 2003) and Chauhan and Saxena (1985), carried out during the thingtam event of 1977-78, and from opportunistic observations by the present authors between 2004 and 2008. These studies suggest a fundamental commonality in rodent ecology with the better-studied upland agroecosystems of Laos (Khamphoukeo et al 2003, Aplin et al 2007, Douangboupha et al 2009). During nonmasting years in Laos, the annual population cycle of rats in the jhum environment is largely determined by the monsoonal pattern. Through the dry season, jhum fields stand in fallow and productivity in the forests is probably also low. Rats living in these environments show little or no reproductive activity through this period. With the onset of monsoonal rains, plant growth and insect activity increase in both forests and fields, and rats show the first signs of reproductive activity. Rodent damage to jhum crops increases through the cropping season as more young emerge from burrows to feed on the maturing crops. Harvest puts an end to this period of rapid growth in field-rat populations, as many are forced to fall back on the less prodigious forest resources. Where people reside close to their cropping areas, some rats (most notably R. rattus) follow the harvested crop into village habitats, where they continue to breed through the fallow period, feeding on stored grain. Estimates from Laos and Myanmar suggest that rats usually consume between 5% and 15% of the crop each year prior to harvest, with further losses during storage (Schiller et al 1999, Singleton 2003, Singleton et al 2010). Mizo farmers reported similar crop losses to rodents in “normal” years. Chauhan
Ken Aplin and James Lalsiamliana (1981, 2003) reported strongly seasonal breeding in *R. rattus* and *R. nitidus*, with high reproductive activity in July to October and a cessation of breeding from January to April. Rats captured during Aplin’s pre-маutam visits to Mizoram in 2004 and 2005 also showed reproductive activity consistent with this wider pattern (Table 1).

Cultural and historical background

Northeastern India is also a Suture Zone in a cultural sense. Its indigenous people belong to a number of tribal minorities, all of whom have strong ethnic affiliations with inhabitants of southern China rather than with the more proximate peoples of the Indian subcontinent. Mizo people themselves most likely migrated to their present homeland in several waves, starting around 500 years ago, and they have close relatives in Shan State and the Chin Hills of Myanmar, and in the Chittagong Hill Tracts of Bangladesh.

The recent political history of Mizoram is of special interest—not least because of the unique role played by rodents in shaping the course of events (Hazarika 1995, Nag 1999). Prior to colonial times, Mizo politics were dominated by a process of local alliances, raiding, and retaliation. In 1895, the Mizo Hills were formally proclaimed part of British India and, in 1898, became known as the Lushai Hills District of Assam State, with Aizawl as its headquarters. Missionaries arrived around the same time and today most ethnic Mizos are Christian. In 1919, the Lushai Hills along with some other hill districts were declared a Backward Tract and, in 1935, all of the tribal districts of Assam, including the Lushai Hills, were declared an Excluded Area.

As India prepared for independence following the end of World War II, Mizo people began to express political will. Various representations were made to the emergent Indian government by the Mizo Common People’s Union (a group formed on 9 April 1946 and later renamed the Mizo Union) and also by a splinter group, the United Mizo Freedom Organization (UMFO), which preferred that Lushai Hills join Burma after independence. A degree of autonomy for the tribal regions was granted by the Indian government and administered through the Lushai Hills Autonomous District Council, which came into being in 1952. However, there was general dissatisfaction with this arrangement and, in 1955, tribal leaders met in Aizawl to form a new political party, the Eastern India Trader Union (EITU), which incorporated former members of both the Mizo Union and the UMFO.

In 1959, political maneuvers were interrupted by the arrival of мautam. Widespread flowering and death of *Mau* bamboo throughout the Mizo Hills was followed by plagues of rats that devoured crops and infested houses, consuming stored foods and possessions. Very little rice or other produce was harvested and many Mizos turned to the jungle to subsist on roots and leaves. Famine became widespread and many people died of malnutrition and diseases, notably including cholera. Although many organizations tried to provide famine relief, the ruggedness of the terrain and a limited network of established roads hindered movement of people and goods. One organization that figured prominently in these efforts was the Mizo Cultural Society, first formed in 1955. In March 1960, it changed its name to Mautam Front and soon...
thereafter to Mizo National Famine Front (MNFF), and it proved an effective body, not only for the distribution of relief but also for drawing wider attention to the plight of the Mizo people.

By 1960, mautam was largely a spent force. However, the experience had reinforced Mizo views of self-reliance and self-determination; the MNFF lived on and, in October 1961, it transformed itself into the Mizo National Front (MNF), with the expressed goal of achieving independence for Greater Mizoram (i.e., all of the territory occupied by the Mizo people). Political frustration soon reached a boiling point and, on 28 February 1966, large-scale violent disturbances broke out in numerous centers, including Aizawl and Lunglei. The insurgency launched on that day was to last for a full 20 years. However, a parallel process of political negotiations through that period brought a stepwise move toward peace and self-determination, first with recognition in 1972 of a Union Territory of Mizoram, next with a cease-fire in June 1986, and finally, on 20 February 1987, with the establishment of Mizoram as the 23rd state of the Indian Union. Notably, leading members of the once-outlawed MNF assumed prominent roles in the new state government, including the position of chief secretary. Rarely has armed conflict culminated in such a favorable political outcome for the insurgents. And, never before or since can a political movement trace its origin to an infestation of rats!

Past bamboo flowering events and rodent outbreaks in Mizoram

Dread and fascination often go hand in hand. As do adversity and community. A central pillar of Mizo society is Tlawmngaihna, an untranslatable term that implies an obligation of all members of society to be hospitable, kind, unselfish, and helpful to others. Mizo people link this concept to another, Tampui Mitthi, or Great Famine, which embodies the relentless cycle of hardship brought by natural causes that Mizo people endure, paramount among them the events associated with the mass flowering and death of two locally dominant bamboos, Mau (Melocanna baccifera) and Rawthing (Bambusa tulda).

Clues from deeper history

The phenomenon of bamboo flowering is deeply embedded in Mizo oral history and it is also a dominant theme running through the written history since colonial times. Taken in combination, these two major sources are a remarkably rich source of relevant information on past environmental events. The State Archive of Mizoram in Aizawl contains many hundreds of folders of information on the early colonial history of the Lushai Hills, and references to bamboo flowering, rats, food shortages, and food relief are commonplace. Though much of this information remains to be tapped, significant details are available from a number of secondary sources (Rokhuma 1988, Hazarika 1995, Nag 1999).

The earliest military forays into Mizoram by the British, made in the early 1880s in response to repeated Mizo raids onto the Sylhet Plains, encountered a people in the grip of a famine that they attributed to plagues of rats. Colonel E.R. Elles stated in a military report on the Chin Lushai Hills for 1881 that...
The famine arose from the depredations of rats, who multiplied exceedingly the previous year owing to the ample food they obtained from the seedling of bamboos (cited in Rokhuma 1988: 98).

In this case, the rat outbreak was attributed to widespread flowering of Rawthing bamboo (Bambusa tulda). According to one source, 15,000 people may have died as a consequence of the famine of 1881 (Chatterjee 1995: 13), out of a total regional population probably numbering less than 90,000.

As British administration and the various Mission Societies extended their influence, a more general awareness came about of the remarkable capacity of Mizo people to predict these events based on their understanding of regular (but noncoincident) flowering cycles for two locally abundant bamboo species. Prolific and widespread flowering of Mau bamboo (Melocanna baccifera) and a subsequent rodent outbreak and famine were widely anticipated by Mizo people for 1910-11. By this time, sufficient administration was in place for the bamboo flowering events, rodent outbreaks, and famines to be documented by both the district administration and various Mission Societies (Rokhuma 1988, Nag 1999).

Rokhuma (1988: 101-103) provided the most detailed summary to date of the events of the 1910-12 mautam. He noted that mautam was presaged by the swarming of a large pentatomid bug known locally as Thangnang (Udonga montana). This appeared in 1909 and 1910 and was consumed by Mizo people in huge quantities. Flowering of Melocanna bamboo occurred in 1910 in eastern parts of Mizoram and was followed by severe, albeit localized, crop damage by rats. The following year, Melocanna flowered everywhere and rat numbers were also seen to increase dramatically, with fields under attack “in the beginning of the autumn season” (i.e., August) (Rokhuma 1988: 101). A system of bounty payments was introduced in 1912 by the district administration and this led to the presentation of 179,015 rat tails. By then, however, damage to crops was already severe and widespread, and many people took to the road in search of surplus food from the previous year. Some additional rice was sourced by the administration in adjoining states and this was distributed by river and over land. However, the limited road network and generally poor communications meant that many people were unsupported. The population of what is now Mizoram in 1911 was probably around 91,000 people. There appears to be no estimate of mortality resulting from the 1910-12 mautam. Several large groups of Mizo people migrated west into Tripura State, where they still reside.

Rawthing bamboo flowered again across large areas of Mizoram in 1929 and 1930 and rats were observed to cause heavy damage in both years. However, good harvests in the preceding years had allowed the distribution of surplus; hence, famine impacts were localized and quickly countered (Rokhuma 1988: 104-106). A total of 1,500,000 rats and squirrels are said to have been killed during this period through the use of locally made rat traps and Hnamtur (Gelsemium elegans), the latter “a kind of creeping plant whose roots are very effective poison to rodents” (Rokhuma 1988: 154-155).

The 1958-60 mautam

Mautam returned to Mizoram in 1958. This time, it was documented in even greater detail, most diligently by Pu Rokhuma, a government employee and resident of Aizawl.
Rokhuma’s records of this period fill many filing cabinets at his home (personal observation, May 2009) and are summarized in his self-published booklet (Rokhuma 1988: 110-113, 140-147). According to Rokhuma’s account, mautam itself was preceded in 1956 by the gregarious flowering of another species of bamboo known to Mizo people as Phulrua (Dendrocalamus hamiltoni). In 1957, Melocanna itself flowered and produced fruit at scattered localities but the rice harvest was mostly unaffected. The following year, gregarious flowering and fruiting of Melocanna commenced in the eastern parts of the district, where a “great multitude of rats fed on these bamboo fruits,” with extensive crop damage around the time of harvest (Rokhuma 1988: 111). Elsewhere in the region, good harvests were obtained in most areas. In 1959, Melocanna flowering and fruiting activity occurred throughout the region and “the rate of increase in rat population was beyond imagination” (ibid). By August, the Melocanna fruit was observed to be all eaten up and destruction of rice and other crops intensified. Crop losses were both widespread and severe, and the total regional harvest in October 1959 was judged sufficient to last only until February 1960. Although rat populations were observed to crash in 1960 with the absence of further Melocanna fruiting, poor harvests continued over several more years, and not until 1964 were good harvests obtained. Low harvests in the intervening years were blamed on drought conditions in 1960 followed by extensive wildfires resulting in a loss of soil fertility, and on the impacts of insect pests and diseases (Rokhuma 1988: 112-113).

Preparation for the 1958-60 mautam had commenced in 1951 with the formation of the Anti-Famine Campaign Organization (AFCO). The preparatory objectives of AFCO included the general improvement of both jhum methods and practices and transportation infrastructure, the diversification of cropping (including the promotion of large-scale banana production), and awareness training on the strategic use of rodenticides (Rokhuma 1988: 119-127). Many of the suggested famine-relief measures, including the planned distribution of rodenticide, were not supported by the Assam State government, which displayed open skepticism about the predicted famine. As a result, it was not until severe famine conditions became widespread in late 1959 that countermeasures were taken. Although these included rice importation, with distribution via air drops, motor boats, and jeeps (Rokhuma 1988: 142-146), too little assistance came too late for many communities. The number of deaths from malnutrition and associated diseases through this period is not accurately recorded; however, local sources estimated the number of excess deaths through this period at around 10,000, or about 5% of the total population of around 200,000 people (Hazarika 1995, Nag 1999). A high rate of infant mortality and local outbreaks of cholera contributed to this total, both probably exacerbated by malnutrition among many populations.

The 1976-77 thingtam
The anticipated thingtam of 1976-77 was treated with greater respect. Ecological studies of this event were carried out by several research groups: the Zoological Survey of India (Chauhan 1981, 2003, Chauhan and Saxena 1985, Pillai 1980); the Northeastern Hill University in Shillong (Prabhakaran and Michael 1980, Trivedi and Tripathi 1980); and the Indian Council for Agricultural Research (ICAR) Research
Complex in Shillong (Das and Sachan 1980). Rokhuma (1988) also maintained his vigil through this period and his accounts contain many important details regarding both the environmental events and governmental responses.

The ecological studies carried out through the 1976-77 thingtam failed to produce any clear association between bamboo flowering and rodent outbreaks. In a recent review of this evidence, Chauhan (2003: 267) remarked that “flowering of the bamboo had no measurable effect on rodent population dynamics.” More specifically, he noted that despite a constant vigil, no sign of rat migration from jhum to bamboo forest or vice versa was observed in Mizoram during flowering of B. tulda. The rats mainly inhabited paddy fields, and showed variation in their numbers in relation to the crop cycle during the flowering of B. tulda. Only a few rats were noticed in the forests during this period (Chauhan 2003: 270).

However, in assessing these comments, it is important to note Chauhan’s admission that “Only in a very few places in the northeastern region did the bamboo flowering result in seed formation” (ibid) and also that his field monitoring activities were carried out exclusively in active and fallow jhum fields, rather than in established bamboo forest. Other scientists involved in the assessment of bamboo flowering events in Mizoram in 1976-77 seemed more open to the possible role of bamboo masting in stimulating rodent outbreaks (e.g., Das and Sachan 1980, Prabhakaran and Michael 1980, Trivedi and Tripathi 1980). However, in every case, their conclusions were qualified with reference to other possible ecological factors, including a decline of predators, the role of immigration, and general imbalances in the jhum ecosystem. Several of these researchers commented on the myriad difficulties of studying this particular phenomenon, including the large scale of the events, the difficult terrain and impenetrable bamboo forests, and the generally elusive rodents.

The course and impacts of the 1976-77 thingtam were recorded in even greater detail by Rokhuma (1988: 116-118, 147-157). He notes that gregarious flowering of Rawthing bamboo commenced in 1975 in Tripura State to the east of Mizoram but not until 1976 in the west of Mizoram. At that time, people reported “a swarm of rats came from the neighbouring Tripura” (1988: 116). More widespread flowering occurred in 1977 and “rats multiplied exceedingly great in numbers” (ibid). Some farmers had elected not to grow rice in anticipation of thingtam and many had grown ginger in response to government directives to produce cash crops rather than rice. However, according to Rokhuma (1988: 116), “it posed great difficulty in marketing ... (and) … thousands of mounds (sic) were unsold and left on the roadside rotting.”

Preparations for the 1976-77 thingtam had commenced in February 1975 with the formation of the Rodent Control Committee in Mizoram State. The main objectives of the committee were to coordinate rat eradication measures across the state. After reports of widespread crop damage were received in the autumn of 1976, the Committee instigated two measures: a bounty scheme of 2 rupees per tail and a plan for large-scale distribution of rodenticide, including zinc phosphide, aluminum sulfide, and warfarin. In addition, all farmers were urged to grow high-yielding early rice varieties as well as tapioca and maize on a large scale, for which seeds and stumps were supplied. Records of the bounty scheme indicate that 553,045 rats were killed in
1976, mainly from the southern area of Mizoram. The highest number of rats killed by an individual person in 1976 was 7,000 (Rokhuma 1988: 152-153). During 1977, bounty was paid on a total of 2,616,616 rat tails. Groups of students from various schools and colleges took part in systematic rat annihilation, with one group of 150 students from Pachhunga University College reportedly killing 22,133 rats “by means of various rat poisons and new tactics” (Rokhuma 1988: 155).

**Strange events and speculation**

Historical and anecdotal sources concerning *mautam* contain numerous references to extraordinary events and magical possibilities. Rokhuma (1988: 140) notes that both the 1911 and 1958 *mautam* were presaged by swarming of *Thangnang* bugs and by the passage of comets (Haley’s in 1910, Mrkos in August 1957), which for Mizo people is a sign of impending misfortune (Rokhuma 1988; C. Lalbiaknema, interview with V. Grossman, 14 November 2002).

Many accounts of *mautam* refer to the rapidity of crop damage and for some people this was cause for doubt that rats were responsible. For example,

In 1959 we had a 1.5 acre plot of shifting cultivation. The previous day we thought the *jhum* would not be very much affected. … In the night the paddy was all gone. The grain was all plucked out and taken away. On November 2 the paddy was still standing but all the grain heads were gone next day. … It’s a mystery how this happened. … It might have been birds, but no one knows how it happened. The tops were all cut off. The day before everything was fine; the grain was all there. (C. Lalbiaknema, interview with V. Grossman, 14 November 2002.)

Another recurrent theme in accounts of the rodent outbreaks is sightings of large numbers of rats moving together in a coordinated manner, sometimes described as “rat armies.” According to Rokhuma (1988: 111), a man called Sanga of Lungleng Village observed a swarm of rats at dusk crossing a footpath “in thousands just as the hailstorm … the trail they left behind was just like those of the herd of wild boars.” The sound of large numbers of rats moving across the landscape was sometimes described as being like heavy wind or a train approaching. Occasionally, these accounts were elaborated into the realm of the implausible—a newspaper account of 1960 (Amrita Baar Patrika 1960, cited by Pillai 1980) reported an instance of two rat armies that ignored crops to do battle with each other, the combined forces of 30,000 leaving behind 3,000 dead.

A final noteworthy observation of rat behavior during the 1958 *mautam* is mentioned in the interview transcript with C. Lalbiaknema—the finding after crop destruction in the *jhum* field of “up to ten live rats in the holes (burrows).” Most of the rat species found in Mizoram are essentially solitary animals; outside of masting-outbreak periods, it is rare to find more than one or two adults in a burrow, aside from a female with a litter of small dependent pups.

Many reports of rodent outbreaks during *mautam* and *thingtam* include speculation about the causation of the marked rodent population increases. Nearly all mention the avid consumption of bamboo fruits. For some, this seems sufficient explanation of the population increase. Others speculate further that it allows more young to survive.
due to a reduction in cannibalism of young under conditions of food surplus (Rokhuma 1988), or that the fruit contains special properties that either encourage mating, allow more rapid development of the young, or stimulate the production of larger numbers of young (Mahadevan et al 1961). For others, the increase in rat numbers is too great to be explained solely in terms of a local population increase, with the implication that large-scale immigration of rats must be occurring to take advantage of the locally abundant food (Das and Sachan 1980).

**Studies of the 2007-08 mautam**

As the date of the latest mautam approached, various preparations were made to both document and mitigate the impacts of the anticipated events. The official response included formation under the suggestion of the chief minister of the Mizoram government of the **Bamboo Flowering and Famine Combat Scheme** (BAFFACOS) (Government of Mizoram, undated a,b), whose interim achievements were reported several years later (Government of Mizoram, undated c).

Under the broader umbrella of BAFFACOS, staff of the Agriculture Department, most notably Lalsiamliana, variously facilitated and coordinated work in Mizoram by a number of external researchers. One of these was Dr. Valerie Grossman, then a graduate student of the Fielding Graduate Institute, who undertook participatory action research with Mizo communities to help them prepare for mautam. Her dissertation (Grossman 2004) contains extremely informative transcripts of interviews with Mizo people who had lived through previous rodent outbreaks and a number of these are cited here. Aware that she did not possess sufficient knowledge of rodent biology to offer advice on management actions, Grossman facilitated a visit in 2004 by John B. Bourne, a rodent control specialist from the Department of Agriculture, Alberta, Canada, who offered advice on the most effective use of rodenticides. Subsequently, Lalsiamliana made contact with Aplin, who visited Mizoram on invitation of the minister for agriculture on two occasions (March and November 2004) prior to the commencement of mautam. During these visits, Aplin and Lalsiamliana traveled to various parts of Mizoram, talking to Agriculture Department staff and local farmers, collecting rat specimens for identification of the major pest and nonpest species, and establishing a baseline on rodent ecology through examination of patterns of habitat use and breeding activity. This information was summarized in two unpublished reports presented to the minister for agriculture; each contained recommendations for further research activities and for possible mitigation actions. In November 2004, Mizoram was also visited by a team headed by Dr. Mohan Rao from the National Plant Protection Training Institute, Hyderabad. Their unpublished report to the minister for agriculture contained suggestions for surveillance of rat numbers in jhum fields and for effective rodenticide use in the event of local rodent outbreaks.

Ecological studies of gregarious flowering of *Melocanna baccifera* were conducted by a research team headed by Dr. Shozo Shibata of Kyoto University, and by staff of the Department of Forestry, Mizoram University, principally Dr. F. Lalnunmawia. Attempts by Aplin to secure further funding for more detailed ecological studies running through the mautam were unsuccessful. However, the opportunity arose in
2008 to join a National Geographic team making a documentary about mautam. This led to repeat visits in May, August, and September 2008, during which it was possible to establish a limited monitoring activity in one area and to make more general observations on the flowering and fruiting of *M. baccifera* and its consequences for rodents and people. Aspects of this activity are recorded in the Nova documentary titled “Rat Attack” (www.pbs.org/wgbh/nova/rats/).

The 2005-08 mautam in Mizoram

**Flowering and fruiting of Melocanna baccifera**

Sporadic flowering of *Melocanna* was recorded at three localities in July 2001, at 33 localities in February to July 2002, and more widely between February and July in 2003 to 2006 (Government of Mizoram undated c, Shibata 2009). This sporadic flowering activity resulted in some fruit production but not in the death of the culms.

Gregarious flowering occurred first in the northwestern district of Mamit in January 2005, covering an estimated 500 hectares. Widespread flowering occurred in the eastern, southern, and central districts in 2006, involving approximately 25% of the total area of *Melocanna* forests. Flowering continued throughout Mizoram in 2007 and extended into 2008 in the northwest, with similar phenology each year—flowering commencing in late October to January, followed by fruit production 3–4 months later. In many areas, the majority of *Melocanna* stands flowered in a single year. In some localities, flowering occurred over two consecutive years, usually in different stands but in some instances involving different plants within a single patch of forest. Mamit District was unusual in having both early and late phases of flowering activity. Around Aizawl, where the process was followed closely by the Kyoto University research team (Murata et al 2009, Shibata 2009), gregarious flowering started in November 2006 with shedding of dead leaves from January 2007. Seeds developed on the culms from February and began to fall in large numbers from May 2007. Fallen seed germinated from June, immediately upon the onset of monsoonal rain. Our observations in central and northwestern Mizoram suggest that the gregarious flowering activity of 2007-08 began in late October to November 2007 in all areas but that the timing of fruit production and fruit fall varied considerably. In February 2008, people across the whole of Mamit District worked to clear new *jhum* fields in areas of established *Melocanna* forest. In some localities (e.g., Tlangkhang Village), people reported that falling bamboo fruits posed a serious hazard when cutting the bamboo culms, whereas, in other places (e.g., around Zamuang), the bamboo fruit was at only an early stage of development during bamboo clearing.

The characteristics and total quantity of fruit produced by *M. baccifera* culms varied according to the disturbance history of sampled stands (Lalnunmawia 2008). Undisturbed stands produced heavier fruits (119.0 ± 7.0 g) than stands subjected to intensive harvesting of bamboo shoots (90.5 ± 7.8 g) or burning (72.3 ± 7.8 g). However, this difference was offset by the production of greater numbers of fruit in burned stands. Total fruit production on 25-m² quadrats amounted to 209 kg for undisturbed stands, 195 kg for burned stands, and 64 kg for harvested stands. These
estimates of fruit production equate to staggering values of 25.6–83.6 tons per hectare. Estimates of fruit production in other bamboo species range from around 1 kg of seed per m² (i.e., 10 tons per ha) in Bambusa arundinacea (Gadgil and Prasad 1984) to 3.6 kg per m² (36 tons per ha) in Dendrocalamus strictus (Janzen 1976: 355). At Zamuang, fruiting of Melocanna was observed to be asynchronous on a single culm, with well-developed fruits present on some spikelets while others arising from different nodes were still at the flowering stage. Fruit production from a single plant thus seems to be spread over a period of many months.

One of the most remarkable features of fruit production is the capacity of M. baccifera to reproduce directly from the rhizomes (Fig. 3). Even where regrowth of culms in jhum areas is countered by continued weeding of new culms, the production of spikelets continues unabated and fruit litters the ground. For all practical purposes, the reproductive episode for Melocanna bamboo thus appears unstoppable.

Two other bamboo species underwent gregarious flowering broadly coincident with that of M. baccifera—Dendrocalamus hamiltoni, known as Phulrua to Mizo people, and Pseudostachyum polymorphum, known as Chal or Rawte. The former species appears to have a 48-year reproductive cycle, synchronized with that of M. baccifera, and is the dominant bamboo species in some parts of Mizoram. The fruits of D. hamiltoni resemble grains of rice and develop in clusters of 150–190 grains (Lalsiamliana, personal observation), while those of P. polymorphum resemble those of M. baccifera but are much smaller, averaging 6 g in weight (Lalsiamliana, personal observation). Fruiting from rhizomes was not observed for either species.

Patterns of crop damage
Exceptionally heavy losses in both jhum and irrigated rice fields occurred in the eastern and central parts of Mizoram in 2006-07, and in the western parts in 2008. Figures for total jhum and irrigated rice production for Mizoram during each of these years show extreme depressions, with jhum production the worst hit—state-wide yields of just over 10,000 tons, compared with >60,000 tons through the preceding five years (Fig. 4). At no time since 1981, when the keeping of state records began, had rice production been so meager. In all areas, losses to maize were even more extreme than for rice, with almost no maize harvested at all during these periods.

These rather impersonal figures were given extra poignancy through interviews with affected farmers. At the village of Vawngawn in Mamit District, farmers had observed rat populations building inside the forest, which in this locality is a mixture of secondary evergreen forest and bamboo forest. In April, rats removed many of the maize seeds immediately after planting, and then consumed all of the surviving early-maturing maize over a period of 4–5 days in June. Later, they destroyed the slow-maturing maize and in August to early September they attacked the rice when it was approximately half-way through ripening, with most jhums devastated within a few days from the first signs of damage. Of 52 families in the village, only three managed to harvest any rice, and they obtained only 20% of the expected yield. No one among the people interviewed had any personal experience of crop destruction on such a scale or of such rapidity, but some said that it had happened in the time of their
Fig. 3. Melocanna baccifera fruits produced on spikelets growing out of rhizomes in a patch of forest cleared and burned for jhum planting. Photographed near Zamuang in May 2008.

Fig. 4. Total rice production for whole of Mizoram for the entire period of record-keeping, 1981-2008. Production from jhum and from irrigated lowland fields is shown separately.
parents, during the previous *mautam*. Testimony of this kind is immediate, dramatic, highly consistent, and completely believable.

At the nearby village of Damdiai, large cropping areas had also suffered extreme damage in late 2007, with few farmers able to harvest any rice. Here, the interviews held in May 2008 focused on details of rat behavior during and after the periods of rapid destruction. Farmers remarked on several unusual aspects. Whereas the usual field rat (*Rattus rattus*, known to Mizos as *Zuin* or *Zuchang*) has a girth equivalent to a man’s wrist, making it too large to sit atop a rice tiller, the damage done during outbreaks was said to have been done by smaller animals that could feed on individual grains within a panicle or snip through the stem of the panicle. Fields damaged during these events thus tend to have the heads damaged or removed, with most of the tillers left intact. Some people speculated that this might be caused by birds or even bats. Others claimed to have seen large numbers of small rodents sitting on top of the rice crop and referred to these as *Chaichim* (a Mizo name usually reserved for species of the genus *Mus*). The same group of farmers commented that, in the days after their crops were destroyed, they had dug burrows around the edges of the fields and found large numbers of rats sheltering together. At other times, it would be more usual to find only one rat per burrow or perhaps a mother with young. They also remarked that many rats had moved into the village after the period of crop destruction and that the village rat population had remained high ever since. When asked whether this had caused health problems, one young farmer noted that an old man had dropped dead (quite possibly of shock!) when a rat had leaped onto his back at night.

One of the more perplexing features of these reports of crop damage during *mautam* is the marked variability in outcomes at several scales. Of two villages in close proximity, one might suffer high damage and the other go largely unscathed. And, even within a single field complex, one group of fields might be spared while others, no more than a few hundred meters distant, might be devastated. This variability speaks volumes against simple explanations of crop damage, and encourages a search for mechanisms that involve simple thresholds or, perhaps, divergent outcomes based on conditions at particular critical points in time.

Observations on rat abundance and reproduction

Unusually high rat numbers were reported to the Mizoram State Agriculture Department in every area where *M. baccifera* underwent gregarious flowering. A bounty scheme was introduced to provide supplementary income for farmers affected by rodent outbreaks and to derive some measure of the relative abundance of rodents in different areas. A total of 1,400,000 tails were presented in 2007 for a payment of 2 rupees per tail. A sample of approximately 30,000 of these tails was stored for closer examination. This was done by Aplin in May 2008. The vast majority (probably >95%) of the tails were found to be derived from species of *Rattus*, with smaller numbers derived from species of *Beryllmys*, *Leopoldamys*, *Niviventer*, *Mus*, *Tupaia*, and an unidentified squirrel. This particular sample was derived from Champhai District in the east of Mizoram. Tails of the two larger *Rattus* species found in Mizoram (*R. rattus* and *R. nitidus*) were indistinguishable.
Monitoring activities were established in May 2008 near the village of Zamuang in Mamit District (Fig. 5). In this area, some *M. baccifera* stands had undergone gregarious flowering in 2005 but large stands of the same species had commenced flowering in late 2007. By the time of our first visit to this site in mid-May 2005, the culms were laden with maturing fruits (Fig. 6), with a smaller number already fallen to the ground. Monitoring was established at two sites separated by approximately 10 km, with monitoring conducted in both established *Melocanna* forest and in a recently cleared *jhum* field at each site (Fig. 7). Rat activity at each site was monitored by four methods: (1) trapping with baited cage traps, (2) trapping with locally manufactured traditional snares (Fig. 8), (3) setting of wax candle blocks to record chewing activity, and (4) setting of grease-covered tracking tiles to record footprints. For each habitat, the monitoring effort comprised 16 cage traps, 15 snares, 15 wax blocks, and 15 tracking tiles. The snares, tiles, and wax blocks were set at a total of 15 fixed monitoring stations per habitat, with a minimum distance of 20 m between the stations. The cage traps were interspersed between and around these stations and the trap position was changed every few days to optimize capture rates. Grease was used on the tiles because of the high probability of regular, heavy monsoonal rain beginning in May. All cage traps were set on the ground in both forest and *jhum* habitats, whereas the local snares were usually set on fallen culms or logs in the forest and on the ground around the margin of the *jhum* fields. The occurrence of daytime and nighttime rainfall was noted for each day. All captured animals were euthanized and preserved whole in ethanol for examination of reproductive activity. The monitoring was carried out by Mizo farmers after training, and run continuously from 10 June 2008 until 13 August 2008. At this time, it was discontinued due to other demands on the time of the project participants.

The monitoring activity at Zamuang produced very low capture rates in both habitats, with 19 individuals trapped or snared at the two sites (Table 1). At one site, the forest habitat produced eight *R. rattus*, two *Berylmys berdmorei*, one *Tupaia* sp., and one *Herpestes javanicus* (small Indian mongoose). The *jhum* habitat at this site produced 13 *R. rattus*, one *Tupaia* sp., and one *Suncus* sp. (a shrew). At the second site, the two habitat samples were unfortunately mixed but the combined sample included 11 *R. rattus*, two *Tupaia* sp., and one *Callosciurus* sp. (a tree squirrel). At all monitoring locations, the majority of captures were made in early August and the *R. rattus* samples were dominated by immature individuals. The few adult females captured at these sites were either pregnant or showed recent uterine scars. Two immature male *R. rattus* captured in early June had snout to vent lengths of 85 and 90 mm; these were judged likely to have resulted from aseasonal breeding in the early months of 2008.

At both sites, the tracking tiles only rarely recorded rat activity through June and July (Table 2). This pattern changed abruptly with the onset of regular tracking tile activity, with the change occurring on 4 August in both habitats at one site, and on 8 August in both habitats at the other site. Marking of wax blocks also showed a sudden increase at the same time. The increase in rat activity at both sites did not correspond to any change in rainfall pattern and it seems likely that both sites expe-
Fig. 5. Typical Mizoram scenery during a Melocanna masting event, photographed near Zamuang in May 2008. Rolling hills in a broad valley system are blanketed with Melocanna forest, most of which has flowered and is now in the process of drying. People from several villages conduct their jhum agriculture within this landscape. A cleared jhum with associated field hut is visible near the center of the image.

Fig. 6. Profuse fruiting in a heavily disturbed stand of Melocanna baccifera, photographed near Zamuang in May 2008.
Fig. 7. One of two monitoring sites established in the vicinity of Zamuang, photographed in May 2008. Burned bamboo culms in the foreground show that the *jhum* field was cut from *Melocanna* forest. Masting bamboo forest surrounds the *jhum* field on all sides.

Fig. 8. Mizo field assistants setting a traditional snare in May 2008 as part of the monitoring activities conducted in the vicinity of Zamuang. Fallen *Melocanna* fruits are visible on the forest floor but no germination has taken place, pending the onset of the monsoon.
rienced an abrupt change either in patterns of rodent activity or in rodent abundance at this time. One possibility explored in the narrative of “Rat Attack” is that a highly synchronized onset of breeding activity in *R. rattus*, perhaps stimulated by the first maturation to palatability of *Melocanna* fruits, might lead to the more or less simultaneous emergence upon weaning of a cohort of young, giving a “pulsed” pattern of population increase.

Many *Melocanna* fruits were examined during this period but few showed signs of having been consumed. Those that did tended to be still attached to the culms but positioned close to the ground. A burrow located in bamboo forest near Zamuang was excavated on 24 May 2008. It contained partially consumed *Melocanna* fruits and a

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Table 1. Results obtained using four different population monitoring methods at two localities in the vicinity of Zamuang. Bamboo forest and *jhum* habitats were sampled at each locality. Each habitat was sampled at 15 stations (i.e., one snare, one tracking tile, one wax block) per night, with 16 cage traps set in the same general area. The daily results are pooled for each week of monitoring effort. Monitoring at Site 2 commenced 1 week earlier than at Site 1. The values are the number of positive results over the full week of effort, that is, for Week 1 at Site 1, 16 cage traps set for 7 nights (total of 112 trap nights) resulted in one capture. Tiles were scored positive if they showed any small mammal footprints; wax blocks if they showed rodent gnaw marks.
Table 2. Details of capture location and date and reproductive status of specimens of *Rattus rattus* captured during fieldwork in Mizoram in 2004 (before *mautam*) and 2008 (under *mautam* conditions). Rats were captured either in *jhum* fields or inside bamboo forest. Codes for the condition of the vagina or testis are TND = testis not descended into scrotum; TPD = testis partially descended into scrotum, epididymal sac small; TPD = testis fully descended into scrotum, epididymal sac large; VIP = vagina imperforate; VP = vagina perforate. Values for lactation and recent scars are N = no; Y = yes. Criteria for assessment of uterine scars are described in Aplin *et al* (2004).

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Ken Aplin and James Lalsiamliana

litter of six furred but as yet unweaned pups of *R. rattus*. Another excavated rodent burrow also contained partially consumed *Melocanna* fruit and it seems likely that fruit was regularly carried into burrows or feeding retreats for consumption, thereby making assessments of rodent activity or seed predation unreliable if based solely on surface counts.

To learn more about breeding activity in forest and *jhum* rat populations, a larger sample of *R. rattus* was obtained in August by snaring and active hunting using nets. This sample included four reproductively mature females with body weights of 92–132 g (Table 1). Embryo and fresh uterine scar counts in these animals were consistent with estimates of litter sizes observed in upland field populations of *R. rattus* in Laos and other parts of Indochina (Aplin et al. 2004), with no suggestion of increased litter size in response to either the quality or quantity of food. However, one adult female caught toward the end of the *mautam* period had an unusually large total uterine scar count (minimum of 42), whereas two were found to be at mid-term pregnancy while also lactating and showing recent uterine scars. Although too few individuals were examined to claim any general trend, there is certainly a suggestion that female *R. rattus* were undergoing more or less continuous breeding through the *mautam* event, with immediate postpartum mating perhaps being more common than under nonmasting conditions. Birth of a new litter would presumably cause the female to eject the previous litter of pups from the burrow at a younger age than might normally occur.

The combined results from our work at Zamuang indicate that breeding in *R. rattus* during the *Melocanna* flowering and fruiting episode was exceptional in two respects: (1) the likely occurrence of aseasonal breeding prior to the onset of monsoonal rain, and (2) the likely increase in proportion of females that give birth to successive litters. In our view, the first of these is likely to be a consequence of the unusual availability of abundant, high-quality food in the form of *Melocanna* fruit at a time when resources are normally scarce. An early onset of breeding might be enough in itself to account for elevated crop damage during *mautam* years, with the early phase of population growth taking place largely within the forest habitat as suggested by many previous *mautam* theorists (e.g., Das and Sachan 1980). Sustained access to high-quality food might also account for more closely spaced litters than usual.

Although the rat population at the Zamuang study site was likely undergoing a rapid increase, all of the *jhums* in this part of Mamit District were harvested in late August to early September, with relatively small losses (estimated at 10–30%) to rodents. In general, damage to rice plants in these fields was limited to areas around the margin in direct proximity to the bamboo forest. In contrast, maize was often heavily damaged by rats, even when the plants were located in the center of the *jhums*, many meters from the forest margin. From this observation, it was clear that rats were moving purposefully through the field to target particular food items but were likely returning to burrows or other sheltering places within the forest. A few weeks after our last visit to Zamuang, farmers reported finding large numbers of dead rats both in the forest and in the harvested *jhums*.

At the nearby village of Tlangkhang in Mamit District, rats were reported to have inflicted heavy damage to a large *jhums* field complex, just prior to the scheduled
harvest. These fields were visited on 25-26 September 2008 and the pattern of damage inspected first-hand. Fourteen out of 37 families had lost their entire crop and no family had harvested more than 50%. Damage was visibly severe in many fields, with almost every rice panicle removed at its base. Rice grain was scattered across the ground but the impression was formed that many panicles had most likely been removed from the field. Maize plants in the same fields were also heavily damaged but this attack seemed to have occurred at an earlier time, as we had seen at Zamuang. Some fields in this jhum complex had suffered close to 100% damage and there was nothing remaining to harvest. However, other nearby fields suffered less damage and harvest was ongoing at the time of our visit. In these fields, piles of straw provided an opportunity to capture rats that might have been involved in the heavy damage to adjoining fields. A sample of 25 rats was duly obtained through the use of nets. This sample proved to contain exclusively R. rattus, all sexually immature individuals, and many of them probably no more than a week or two postweaning. For a field-rat population to be so heavily biased toward very young individuals is, in our view, highly unusual, even for an immediate postharvest sample. On the other hand, we suspect that it is entirely consistent with a population in the final stage of exponential growth, in which the majority of individuals in the population must automatically be very young. These very young rats are presumably the “mice” that farmers reported seeing climbing the rice tillers to feed on the panicle in place or else remove it by snipping through the base.

Questioning of farmers in Tlangkhang suggested that the only major difference in events between there and Zamuang was that the Melocanna bamboo had produced seed earlier in Tlangkhang. This fact was brought home when the farmers described having to wear protective helmets during cutting of bamboo culms in February because the Melocanna fruit was already large and loose on the culms. Early maturation of Melocanna fruit presumably would encourage an even earlier onset of breeding activity in R. rattus, with a correspondingly longer time for a population increase prior to harvest. This notion is encapsulated in Figure 9.

As a final observation, we note that the majority of the damage in the most heavily affected fields is probably done by very young rats. With body weights generally well below 50 g, these immature rats are capable of sitting atop rice tillers to either feed on the grains in situ or snip the panicle at its base. This is precisely the unusual behavior that many farmers reported seeing during mautam and that they tended to attribute to large numbers of mice (Chaichim). This is not to deny that mice (Mus spp.) may not also undergo a population increase during mautam and show the same behavior. However, at least at Tlangkhang there was no evidence for the role of mice, and plenty of very guilty looking baby rats!

Mitigation actions and their effectiveness
The Mizoram government was arguably better prepared (and funded) to meet the crisis of mautam in 2006-08 than ever before. The objectives of BACCAFOS (Mizoram Government undated b) represented a comprehensive program of proactive measures and mitigations to reduce the impact of the 2006-08 mautam both on the livelihoods
of Mizo people and on the Mizoram economy. Not surprisingly perhaps, many of the individual objectives were remarkably similar to those developed in the early 1950s and again in the mid-1970s in preparation for the last mautam and thingtam events. Familiar suggestions include the “need for control of rodent population through proper means,” the “adoption of an intensified and diversified cropping system through mechanization,” improved “connectivity of market linkage,” and assistance for “farmers ... to adopt a more profitable, sustainable, and permanent system of farming.” To avoid excessive crop losses, farmers were to be encouraged to adopt “crop diversification for bamboo shoot production,” to favor “early-maturing rice and maize,”

Fig. 9. Graphical summary of a hypothesis to explain variable outcomes under mautam rodent outbreaks, based on observations and information obtained from interviews at two localities, Zamuang, where the majority of farmers harvested most of their jhum rice, and Tlangkhang, where the majority of farmers lost their entire rice crop to rats. The timing of field preparation, planting, and projected harvest dates were essentially the same between the two localities, as was the flowering time of the Melocanna bamboo. The main contrast was in the timing of intensive bamboo fruit production, which was advanced by at least 6 weeks at Tlangkhang. The shape of the curve illustrating postulated growth of the bamboo forest rat population is hypothetical but not unreasonable given knowledge of seasonal population trends in similar agroecosystems in Laos (Aplin et al 2007, Bouangdoupha et al 2009) and the reproductive potential of the main rat species, Rattus rattus (Aplin et al 2004).
and to plant “alternative crops like ginger, cotton, potato, Jatropha, sugarcane, sweet potato, and oilseeds/pulses.” Compared with earlier planning periods, considerably more attention was paid to the prospective loss of a major bamboo resource in both the short term, following the almost complete die-off of a species of major economic importance, and potentially in the long term if adequate regeneration of the Melocanna forest did not occur (Behari 2006). Plans were made for effective use of Melocanna forests prior to the flowering interval and fears were expressed that rodent damage to Melocanna seed might compromise its future in the region. Others considered the possibility of reducing the dominance of M. baccifera through artificial planting of other bamboo species in the period immediately after Melocanna flowering (Trivedi et al 2002), so as to produce a more diversified bamboo resource for forestry and one that might not create future havoc through gregarious die-off on such a vast scale.

Despite these multitudinous fears and plans, large areas of M. baccifera forest have been undergoing natural regeneration from seed in different parts of Mizoram since 2007 and 2008. And, despite the international focus on the possibility that mautam 2006-08 could initiate widespread famine (e.g., Anonymous 2008), a repeat of the 1956-58 experience, the great majority of people came through relatively unscathed. Largely because of the vastly improved road network that now connects most parts of Mizoram, albeit often in torturous fashion, food relief was usually delivered to those most in need, often through cooperative efforts of the government and various NGOs. At a deeper level, however, many people were badly affected by the events and some of the impacts were probably avoidable. In shades reminiscent of the thingtam of 1976-77, people who had grown cash crops such as turmeric rather than jhum rice were aggrieved that there was no market for their product. Other people who had lost their entire jhum rice crop, though grateful for the provision of food relief, expressed concern about their stock of grain suitable for replanting their jhum fields with desirable rice varieties for the year after mautam. Many problems, both large and small, face the Mizo people as they recover from their most recent experience of mautam—but none are able to counterbalance the pervasive sense that something truly remarkable has just taken place.

Understanding mautam—Do we have all the pieces of the puzzle?

We believe that the answer to this question is a qualified yes. At one level, the phenomenon of mautam is a classic example of a pulsed resource (Ostfeld and Keesing 2000, D’Andrea et al 2007, Yang et al 2008, 2009) and the major outcome is entirely predictable. Melocanna baccifera, a superabundant semelparous masting bamboo, is in the very occasional business of producing huge quantities of highly nutritious fruit. Rattus rattus, a rodent species characterized by its ecological adaptability and high reproductive potential, is at hand to consume the seed to its temporary great advantage, even though it is first presented at a time of year when food is generally scarce and no breeding occurs. That R. rattus should commence breeding in response to this windfall and then subsequently switch its attention to other available food reserves in its local environment, in the form of ripening jhum crops, is similarly consistent with its general propensity for opportunism.
One slightly unusual feature of *Melocanna* masting as a pulsed resource for a rodent is its location in a tropical environment—the best-known and most widely accepted examples are otherwise drawn from the deciduous forests of North America (Wolff 1996, McShea 2000) and from the cool-temperate forests of New Zealand (King 1983, O’Donnell and Phillipson 1996). Another is that this example has people thrown in the mix—people with their own propensity for mythologizing, for turning a simple matter into a tangled puzzle, and, sometimes, for oversimplification of a complex story.

Is *mautam* really so simple? As remarked earlier, one of the features of *mautam* that we find particularly striking is its variability of outcomes, even at quite small spatial scales. To our thinking, the next challenge is to better understand this variability. We suspect that the variability is largely produced by differences in the timing of various links in the chain of connection, especially the timing of *Melocanna* seed production relative to the initiation of cropping and harvest. In our simplistic version of things, earlier seed production means more time for the rat population to increase under the steady supply of food and, hence, greater risk of crop destruction prior to harvest. This notion is eminently testable but to do so with *M. baccifera* will now require a long wait. Alternatively, it might be tested by examining the biological interaction between various other species of masting bamboos and black rats, focusing on bamboo species with contrasting phenology. To do so could shed valuable light on the general issue of variability in ecological systems based on pulsed resources. More importantly perhaps, it might also lead to the development of predictive capability in regard to the numerous other species of semelparous masting bamboos found in both Asia and elsewhere in the world, many of which seem capable of generating rodent outbreaks on time frames much shorter than *M. baccifera* but with similarly dramatic consequences for human livelihoods.

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Notes

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