

21. The Rodent Problem in Madagascar: Agricultural Pest and Threat to Human Health

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Abstract

In Madagascar the rodent problem is linked to one species, the black rat (*Rattus rattus*). This chapter will describe its population dynamics in agro-ecosystems and its impact in agricultural crops, in stored grain, on human health and on the endemic rodent community. The black rat has spread absolutely everywhere: from sea level to more than 2,000 m—in houses, fields and also in the forests. It represents more than 95% of rodent catches in the fields and inside houses. Reproduction of rats living in fields stops during the cold season when their maximum annual abundance is observed. Irrigated rice crops suffer the greatest damage with losses estimated at 2.5% of the harvest. Rodent damage is also important for pluvial rice and to a lesser degree for cassava, sweet potatoes and tomatoes. Damage to cacao and sugar cane are important only in the small, poorly-maintained personal plantations. Plague is undeniably the most important disease linked with rodents in Madagascar. It is endemic to the centre of the island in rural areas located above 800 m and its prevalence is increasing. Rodent control in Madagascar is extremely complex because of the economic difficulties facing the country and because the black rat has displayed such successful colonisation in absolutely all habitats.

Keywords

Black rat, conservation biology, Madagascar, plague, rice fields, rodent control, rodent damage

INTRODUCTION

IN MADAGASCAR, the rodent problem is clearly linked to one species, the black rat (*Rattus rattus*), and concerns both agriculture and public health, as well as conservation biology. Eruptions of rat populations were reported in 1916, 1932 and 1965 (Rakotomanana 1965; Ravoavy 1966; in Zehrer 1999). After the last eruption, black rats were declared a public calamity by the Malagasy state, and agricultural pest management of rodents became state-controlled. With respect to public health, the major disease problem is undeniably the plague (caused by the bacillus *Yersinia pestis*). It spread from the seaports of Madagascar at the end of the last century and during the past 70 years permanent rural foci have existed in the central part of the island, above 800 m. Another major issue is that Madagascar's endemic rodents are threatened with extinction as a result of competition with the black rat in addition to habitat loss. This chapter will examine how this situation arose, and describe the impact of the black rat in agricultural fields, in stored grain, on human health and on the endemic rodent community in Madagascar.

Madagascar is the fourth largest island in the world (after Greenland, New Guinea and Borneo), with a surface area of 587,000 square km. It is 1,600 km long from north to south and 580 km at its widest point. It has been separated from the African continent for 160 million years. The minimum distance to Africa is now 300 km. The first human settlements occurred approximately 2,000

years ago. Significant immigration occurred only 1,000 years ago. The human settlers are of both Asiatic (Indonesian) and African origin. A mountain range, 2,800 m high, divides the island into two from north to south (Figure 1). The east side of the country is more abrupt than the west. The effect of the monsoon and the trade winds on this relief determines the different climates and different types of vegetation within the island. Human activities have significantly changed the vegetation and now the different climatic regions can be characterised by their agricultural landscapes.

The east coast of Madagascar has no dry season and rainfall ranges from 2,000 to 3,000 mm per year. The original type of vegetation is rainforest. This type of forest is in rapid regression, due mostly to 'slash-and-burn' agriculture. The centre of the island, called the highlands, has a high altitude, tropical climate characterised by a cold and dry season from May to October and a hot, rainy season from November to April. Before human settlement, it was a mosaic of forests–savannah. Today, the landscape is totally modified by people, dominated by rice-growing in the valleys and by dry farming on the slopes (mainly corn and cassava). The primary forests are extremely rare, but there are plantations of pine and eucalyptus. The drier, west coast is less populated, and is a mixture of cultivation and pasture. The south is semi-arid with a 10 month dry season, dominated by spiny bush. It is a cattle-rearing region with some small patches of cultivated land.

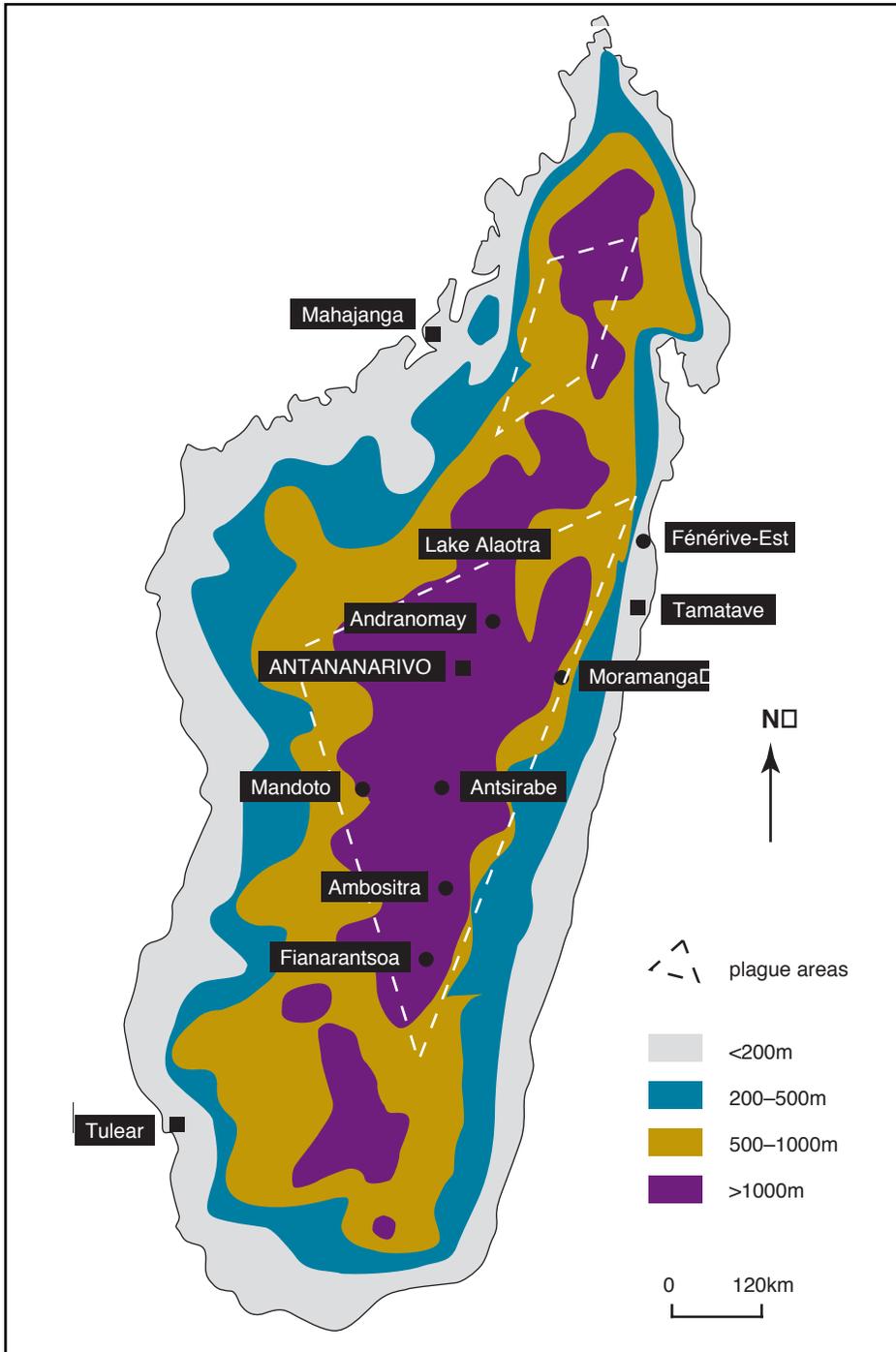


Figure 1.
Map of Madagascar: relief, localisation of plague foci, main towns and study sites.

THE RODENT COMMUNITY IN MADAGASCAR

At least 23 species of rodents exist today in Madagascar (Rakotondravony and Randrianjafy 1998). Like all animal and plant groups on the island, this order is characterised by a high rate of endemism. All the endemic rodents belong to the same sub-family, Nesomyinae, which is divided into 8 genera and 20 species. They live almost exclusively in the forest and their current distribution is limited to the remaining primary forests. *Brachyuromys ramirohitra* and *Nesomys rufus* are captured on farmland but only where this is close to a forest (Rakotondravony and Randrianjafy 1998). The destruction of primary forests in Madagascar, well illustrated by Green and Sussman (1990), threatens the extinction of a great number of animal species. It is particularly the case for endemic rodents of the Nesomyinae sub-family: not only do all of them live in the forests and will therefore suffer from habitat loss, but the fragmentation of these forests makes it easier for the highly competitive black rat to penetrate into the forest. Today, it is common to encounter this species in the primary forests (Goodman 1995).

In Madagascar, populated areas are the exclusive domain of three introduced species, the black rat (*R. rattus*), the Norway rat (*Rattus norvegicus*) and the house mouse (*Mus musculus*). *R. norvegicus* has the most restricted distribution—it is only found in the seaports and the big cities. It has been located in the seaports since the 1930s, but the date of its spread to the highland cities is unknown (Brygoo 1966). At the beginning of the 1980s, it represented more than 80% of

the catches in the capital, Antananarivo (Rakotondravony 1992), which is situated in the centre of the island, and today it has reached nearly 95% (Duplantier et al., unpublished data). Recently, we trapped some individuals in rice fields on the east coast, several km from the cities.

The house mouse is commonly found in houses but is less numerous than the black rat. It is also found in rice fields, savannas and swamp edges, but in low numbers. The date and method of its settlement of Madagascar is not known.

The black rat could have come to Madagascar with the first immigrants approximately 2,000 years ago, however its presence is confirmed only from the 11th century from excavations of an Islamic archaeological site in the north of Madagascar (Rakotozafy 1996; Radimilahy 1997). The shrew *Suncus murinus*, native to Southeast Asia, must have settled in a similar way. Today, the shrew is found all over the island, but it is less abundant than the black rat. The black rat has spread everywhere. It can be found from sea level to more than 2,000 m—in houses, fields and also in the forests. In the highlands and in the middle-west, *R. rattus* represents more than 98% of rodent catches both inside and outside buildings (Duplantier et al., unpublished data). Ratsimanosika (1995) quoted the same figure from the east coast coconut plantations. In the fields of the coastal regions of Tulear (south-west) and Tamatave (east), Rafanomezana (1998a) found 97% of rodents to be *R. rattus*. In the natural forest of Andranomay, in the highlands, *R. rattus* represented two thirds of captures from 1981 to 1982 and the

endemic genus *Eliurus* only one third (Rakotondravony 1992).

Important studies have been undertaken recently on the endemic rodents which are the most threatened order of mammals in Madagascar (Goodman 1995). However, due to their restricted distribution and scarcity, they are of minor importance to agriculture and probably also to human health.

POPULATION BIOLOGY OF THE BLACK RAT

It is a paradox that the black rat is the number one problem of agriculture and public health but little research has been conducted on this species. Different survey programs have been conducted by the Department of Plant Protection (Ministry of Agriculture), but most of the results are still unpublished except for some data on reproduction (Rafanomezana 1999). In fact, only three studies provide accurate data through at least one annual cycle: first, the study conducted at Andranomay (Figure 1) in the 1980s by D. Rakotondravony (1981, 1992) which was mostly carried out in the forest but also in slash-and-burn agriculture areas. This was followed up by a monthly survey in the fields of this locality which was conducted in 1996–97 (Rafanomezana 1999). Secondly, a monthly survey of less than a year was conducted in the Lake Alaotra region (Figure 1), which is one of the most important rice growing regions of the country (Salvioni 1989). Finally, Duplantier et al. (unpublished data) conducted a monthly two-year survey in the villages and fields of the middle-west region around the city of Mandoto (Figure 1).

Reproduction of the black rat

At the edge of the forests and within fields at Andranomay, Rakotondravony (1992) monitored the reproduction in the black rat over two years (1981–1982) (Figure 2). Reproduction begins before the rainy season (November to April) with the maximum number of pregnant females occurring in the middle of this period. These data have been confirmed recently: in 1996–1997 there was an interruption to reproduction in the fields from May to August, with maximum reproduction in January (Rafanomezana 1999).

In Mandoto, reproduction of rats living in houses does not seem to be linked with season (Figure 3; Rahelinirina and Duplantier 1999). However, among the rats trapped outside, no reproduction occurs between July and December—thereafter breeding increases until May and ceases abruptly in June. In this region, reproduction seems to be linked with the harvest of crops rather than rainfall. The first rice harvest in the valleys takes place in December–January, then, from February till May–June, there follows one after another the harvest of corn, cassava, peanuts and pluvial rice on the hills. A second rice harvest can take place in the valleys in May, at the beginning of the dry and cold season (Handschumacher et al. 1999).

In Andranomay, as in Mandoto, these data are confirmed by the age structure of the rat populations: there are no young less than 50 g from May to September in Andranomay, whereas in Mandoto they are least abundant from September to March.

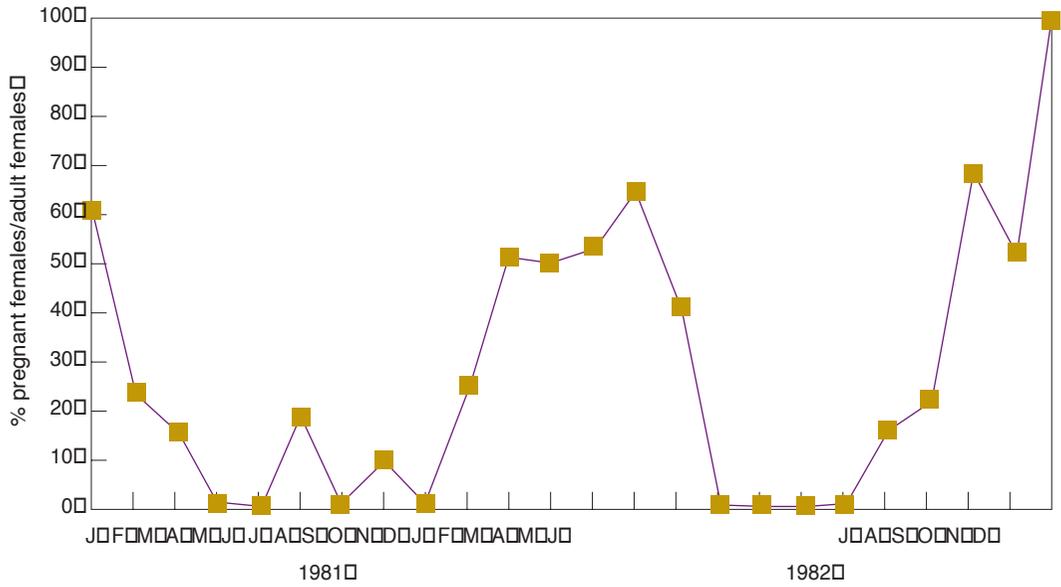


Figure 2. Percentage of pregnant female black rats among adult females trapped monthly in Andranomay forest in 1981–1982 (Rakotondravony 1992).

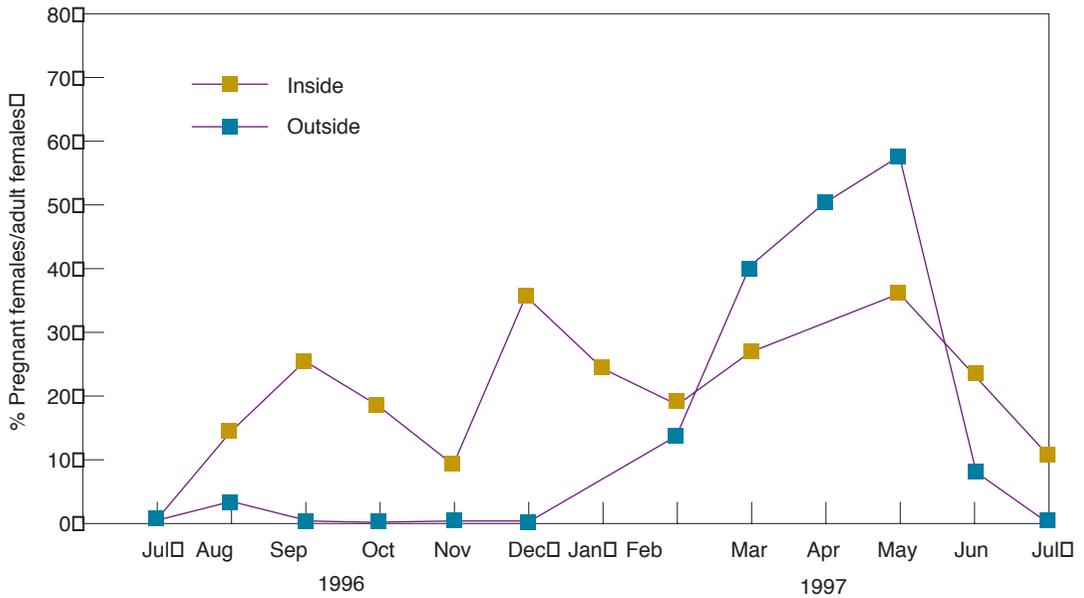


Figure 3. Percentage of pregnant female black rats among adult females trapped monthly inside and outside houses in villages of the middle-west region around Mandoto (Rahelinirina and Duplantier 1999).

In the Lake Alaotra fields, reproduction is concentrated between March and June and seems to be linked with the availability of food in the fields (Salvioni 1989). However, in the presence of a permanent source of food and a shelter, the rats can breed throughout the year.

Differences between these localities are probably linked with the different landscapes and crop types. In the less modified landscape of Andranomay (small slash-and-burn agriculture areas surrounded by forests), rainfall seems to be the most important factor influencing the season of reproduction. By contrast, where irrigated fields are predominant (Mandoto and Lake Alaotra), the seasonality of harvests seems more important.

The aforementioned sites are in the highlands. In coastal regions, specifically Fénériver-Est on the East coast (Figure 1), the minimum number of pregnant females is observed from July to October and the maximum from December to March. In the Tulear region (Figure 1), on the south-west coast, the maximum rate of pregnancy occurs approximately over the same period (January to March) while the minimum occurs earlier, from May to August (Rafanomezana 1999).

Variations in abundance with habitat

In the Mandoto region, we compared four different habitats: houses; sisal fences around cattle pens; dry farming on the hills; and the irrigated fields in the valleys (Duplantier et al., unpublished data). The black rats were most abundant in the sisal fences. The permanent and spiny canopy of the fences provides a good, permanent

refuge and in addition, they are situated near—or even sometimes against—houses where supplies of food are available. Conversely, their abundance is lowest in the dry farming areas because these provide food for rodents only for a short period and the fields are often burned by fire once a year.

In Andranomay, trap success is higher in fields than in the forest (Figure 4; Rakotondravony 1992). Data collected around Lake Alaotra confirm that environments with abundant vegetation and near farms host a high density of rats (Salvioni 1989).

Seasonal variation in abundance

In the fields of Mandoto, we observed a well-marked, seasonal variation in the abundance of rodents with a maximum in July–August in the irrigated fields as well as in the dry farming areas on the hills (Figure 5; Duplantier et al., unpublished data). This was also noted by Salvioni around Lake Alaotra (Salvioni 1989). On the other hand, the fluctuations in population abundance observed in the villages, inside houses and in the sisal fences do not show any marked seasonal variation. In the Andranomay forest, populations peak earlier between February and April (Figure 4; Rakotondravony 1992). Rafanomezana (1999) observed a similar pattern in fields in the same locality.

Thus, the annual maximum abundance of rat populations occurs in the middle of the cold and dry season on the borders of the highlands (Mandoto and Lake Alaotra), and earlier, at the end of the rainy season, in the centre of the highlands (Andranomay).

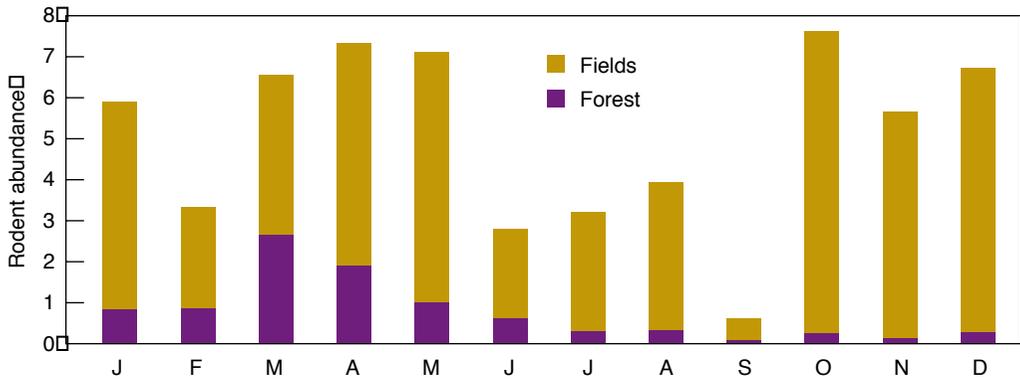


Figure 4. Monthly variations of black rat abundance in Andranomay in forest and field habitats (Rakotondravony 1992).

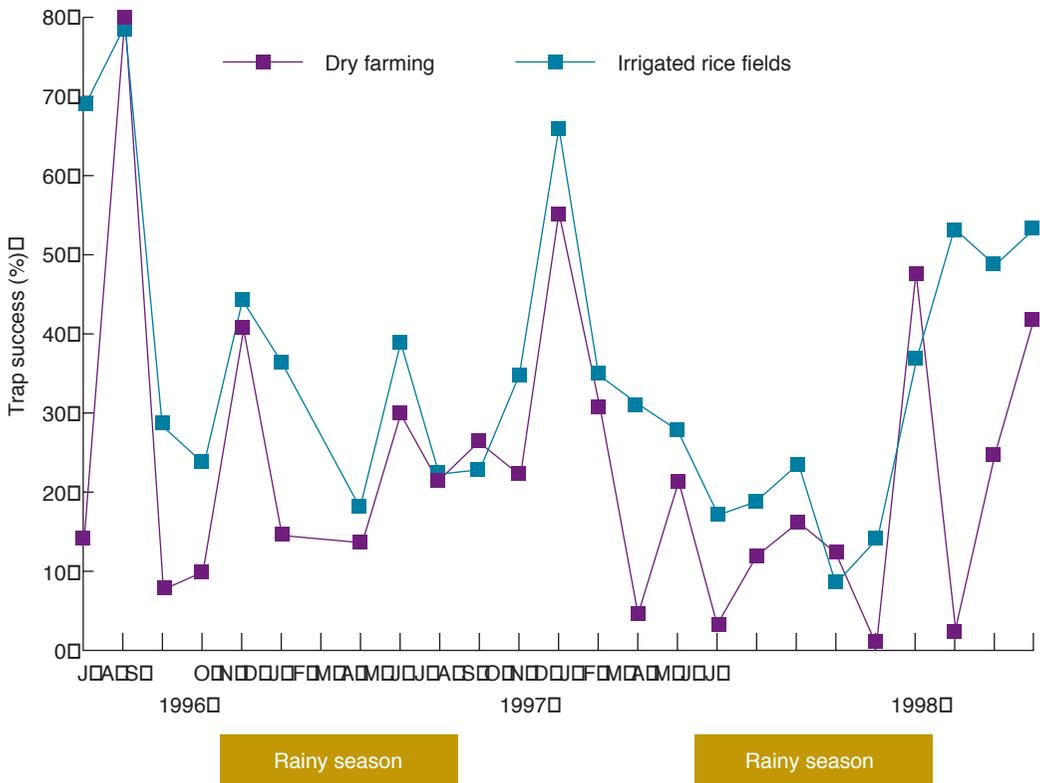


Figure 5. Monthly variations of black rat abundance (trap success per 100 trap nights) in villages of the middle-west region around Mandoto from 1996–1998 associated with (i) dry farming and (ii) irrigated rice fields (Duplantier et al., unpublished data).

Inter-annual variation

Only one long-term study has been undertaken: from 1980 to 1986, in Andranomay (Figure 6; Rakotondravony 1992). Inter-annual variation in the populations of black rats in the forest is low, but there is high variation in the fields, with the maximum abundance about eight times higher than the minimum. In these slash-and-burn fields, harvest differs greatly from one year to another, being especially reliant on the distribution and the total rainfall. However, it is important to note that at the same time, Rakotondravony (1992) observed similar inter-annual variations among urban populations of black rats. During the 1980s, their abundance in the capital (Antananarivo) was double that of normal densities in each of 1981, 1985 and 1989.

DAMAGE IN THE FIELDS

A survey conducted throughout the country showed that 86% of the farmers considered that they had suffered important damage from rats during the previous year. Rodent control was used by 82% of farmers, mostly in the rice fields (29%) and in the granaries (27%); 41% used rodenticides and 27% used traps (Rafanomezana 1998b).

According to Zehrer (1998), it is the irrigated rice that suffers the greatest damage. From surveys conducted in the different rice-producing regions of the country, rodent damage affects around 2.2% of cut stalks, which is equivalent to a loss of 2.5% of the harvest (Raobsoamanitrandrasana 1998). For all the country, the overall annual losses caused by rats are estimated at 62,500 t of rice paddy or 40,000 t of marketable rice.

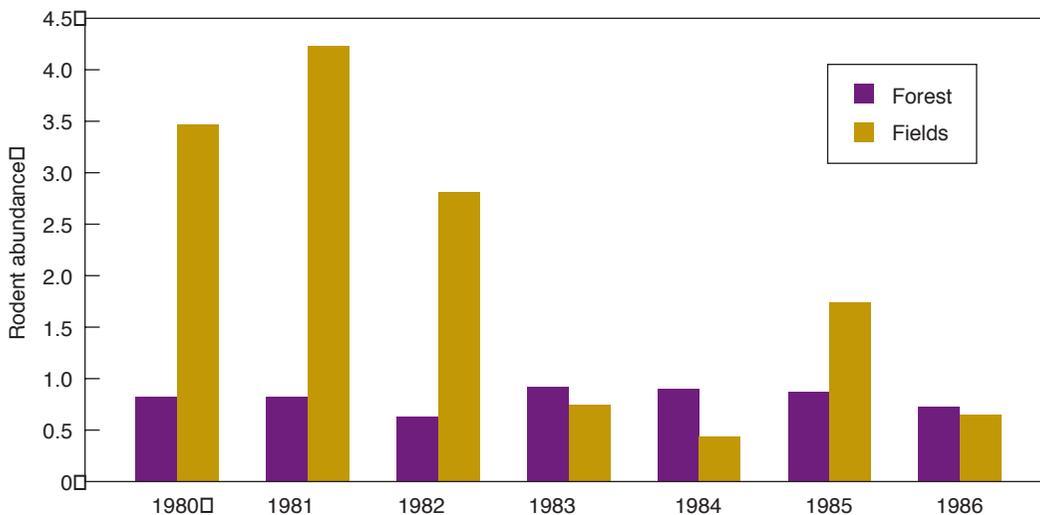


Figure 6. Annual variations of black rat abundance in Andranomay from 1980–1986 in forest and field habitats (Rakotondravony 1992).

Rodent damage is also important on pluvial rice cultivated on the hills or on slash-and-burn areas (Zehrer 1998). Other cereals (wheat, barley and oats) seem to be less affected. With respect to tubers, little damage is observed in potato crops, whereas rodents damage cassava and sweet potatoes. In market garden farms, the more important damage is to tomatoes and, to a lesser degree, to green beans, peas, cabbages and cucumbers.

Among the fruits, the most damage caused by rodents is to pineapples. Damage to jackfruit and papaya has also been observed, but only rarely to bananas. Damage to cacao is important in the small, poorly-maintained personal plantations, but low in industrial plantations—a similar situation applies to sugar cane plantations. According to Rasolozaka (1998), damage caused by rodents is estimated at 19% of the production in the coffee plantations of the east coast. According to Zehrer (1998), although the farmers complain a lot about rat depredation and large quantities of rodenticides are used, the damage is difficult to evaluate. Indeed the majority of imported rodent poisons in the 1980s were used in these coffee plantations. Finally, in the industrial coconut plantations of the east coast, the losses caused by rodent damage are estimated at 2.2% of production (Ratsimanosika 1998).

DAMAGE TO STORED FOODS

Village stores

In rural areas, according to surveys conducted in four of the six provinces of the country, the damage caused by rodents is considered by rural respondents as similar

to that caused by insects (37.5% versus 36.1%). It is only in the south (Tulear region) that the damage caused by rodents is low compared to insect damage (24% versus 58%) (Andriantsileferintsoa 1998). Most harvested crops are stored in heaps, except rice which is generally held in sacks. In the centre, the north and the west of the country, approximately 74% of the rural respondents assert that rodent attacks are continuous. In the south only 21% of farmers feel this to be the case.

With respect to health, the abandonment of traditional granaries by the farmers is a problem. Traditionally, different types of independent granaries, set apart from human houses existed according to the regions (huts built on stilts, cavities dug in the earth etc.) (Rasamoel 1998). Nowadays—for security reasons and for fear of robberies—a great number of farmers prefer to store their cereals in their houses and even in their bedrooms. This increases the possibility of man–rodent contact and thus the risk of disease transmission. This could be one of the causes for the increase in cases of human plague in recent years.

Intermediary stores

These are stores used by the collectors who gather the harvest of the farmers before selling it to retailers or big mills. These structures are rarely rat-proof and the hygiene is rudimentary (Andriantsileferintsoa 1998). However, the duration of storage is limited, and this reduces the importance of damage despite the lack of protection.

Industrial stores

In Madagascar, only the national silo (where seeds are stored) and the warehouses of big commercial companies are rat-proof. According to Andriantsileferintsoa (1998), these companies do not have any serious problems caused by rodents. Their warehouses are new and well-kept, and they regularly use the services of rodent/insect control companies that exist in the capital.

RODENTS AND HEALTH

Buck and Courdurier (1962), as well as Ribot and Coulanges (1982), established the first lists of the main zoonoses in Madagascar. A synthesis of rodent-borne zoonoses was completed recently (Duplantier 1999). The most well known disease linked with rodents is the plague, but rodents are also involved in the transmission of viruses, including hantaviruses. The importance of rodents in the transmission of other diseases in Madagascar is either poorly known (e.g. intestinal bilharziasis), or less important (e.g. rabies). Due to the isolation of the island and its particular community of rodents (a single endemic sub-family with a very restricted distribution), a number of diseases linked with rodents and important elsewhere in the world are unknown on the island (Brygoo 1972). However, the invasion of all the habitats by the black rat allows for rapid propagation of any rodent-borne epidemics throughout Madagascar.

Plague

Plague is undeniably the most important disease linked with rodents in Madagascar (Brygoo 1966). It reached the largest seaports of Madagascar between 1898 and 1907,

during the third pandemic. During the 1920s it reached the highlands, but disappeared from the coastal regions. Thus, the plague became endemic to the centre of the island in rural areas located above 800 m and is now on the increase (Chanteau et al. 1998b). From 1925 until the Second World War, more than one thousand human cases occurred annually. A maximum of more than 3,000 cases was reached in 1935. Mass vaccination campaigns, insect control and the arrival of antibiotics caused an important regression in morbidity and mortality; for more than thirty years, an average of only about fifty cases were reported annually. However, in 1978, the plague reappeared in the capital after a 28-year absence. Since the end of the 1980s, in the country as a whole, the number of human cases increased to more than 100 per year, reached 200 in 1994, and 459 in 1997. In 1991, the human plague reappeared in the seaport of Mahajanga after an absence of 63 years (Chanteau et al. 1998a,b). These official figures include only the cases confirmed by a bacteriological test. Serological tests indicate the number of cases to be two to three times higher (Chanteau et al. 1998a).

The real situation is difficult to estimate. On the one hand, important regions are out of reach of health services, and on the other, information campaigns of the national program of plague control set up since 1991 clearly increased the number of declarations. Despite a low number of official cases compared with other diseases, the economic cost of plague is very high for the Malagasy government, which must cover all the medical expenses in the treatment of this disease. Due to the slowness of the bacteriological diagnostics (several days are

necessary), all cases suspected from clinical examination must be immediately treated. In addition, all persons in contact with those suspicious cases must also undergo an antibiotic treatment. The houses inhabited by people with suspected cases, as well as all the neighbouring houses, must be treated with insecticides by the health services. Therefore, several thousands of people are treated every year.

The plague is transmitted from one rodent to another, and from rodents to humans through haematophagous flea vectors. In most of the plague foci in the world, the reservoirs are wild rodents resistant or less sensitive to the plague bacillus (*Yersinia pestis*). They generally belong to the Sciuridae family (marmots, prairie dogs) and to the Gerbillinae sub-family (gerbils, *Meriones* etc.). The black rat is sensitive to plague and thus cannot be, in principle, the reservoir. It is a commensal rodent which is the link between the wild rodents and humans and hence provokes urban epidemics. The distinctive feature of the Malagasy foci lies in the absence of a wild reservoir; the black rat is involved in all kinds of foci, urban as well as rural (Brygoo 1966). It must also be noted that different fleas are involved depending on the different habitats: *Xenopsylla cheopis* occurs inside houses and *Synopsyllus fonquerniei*, an endemic species, occurs outside. Thus, it seems that in Madagascar the black rat is at the same time the reservoir and the main victim of plague. This paradoxical and unique situation is the result of a balance between the mortality due to plague and the re-colonisation abilities of the black rat, which is spread all over the island, while the plague occurs only in very localised outbreaks.

A program set up in 1996 by the Ministry of Health (DLMT), the Institut Pasteur de Madagascar (IPM) and the Institut de Recherche pour le Développement (IRD, ex ORSTOM—the French Scientific Research Institute for Development through Cooperation) has made it possible to better understand the mechanism of the Malagasy foci. The beginning of the human plague season in the highlands (November) coincides with the minimum abundance of rats outside houses and the annual maximum abundance of fleas. We have shown that particular habitats seem to be important for transmission; i.e. the sisal fences around the cattle pens, situated inside or on the edge of villages. These are where the rodents and the fleas are most abundant, and it is also where the highest antibody seroprevalence against *Y. pestis* was noted among rats. The rural plague occurs only above 800 m, yet the black rat is widespread throughout the island from sea level to more than 2,000 m, and it is the same chromosomal form ($2n = 38$) regardless of the altitude. Inside houses *X. cheopis* is also present independent of the altitude. However, below 800 m, outside the houses, as well as on the rodent fur and in their burrows, we found almost no fleas, while an average of two fleas per rodent was observed during the same season above this altitude (IRD/IPM/DLMT, unpublished data). Thus, it seems that the distribution of the plague in Madagascar is limited by the factors that influence the geographical distribution of the endemic vector, *S. fonquerniei*, which parasitises exclusively rats living outside. It will be important for plague control to monitor the evolution of its distribution for a possible extension of plague foci below the present limit.

Other diseases linked to rodents in Madagascar

Murine typhus is relatively important in Madagascar because Mayoux and Coulanges (1970) found positive serologies in 20% of the rats tested in Antananarivo.

Borreliosis (or relapsing fever) is a disease transmitted by ticks living in the rodent burrows. It has been well known in the west of the country since the 18th century, but there have been no human cases described since the 1950s (Brygoo 1972).

Leishmaniasis is unknown in Madagascar, although infested dogs have been imported (Brygoo 1972) and despite *R. rattus* being a known reservoir in Italy, and *R. rattus* and *R. norvegicus* being suspected reservoirs in many other countries (WHO 1990). According to Brygoo (1972), it was the absence of vectors that has prevented the occurrence of this disease in Madagascar. However in 1982, Ribot and Coulanges reported the discovery of a potential vector, an anthropological phlebotome. Nevertheless, no human cases have been reported.

The absence of leptospirosis in Madagascar is undoubtedly a paradox, as it is a disease which is characteristically associated with rice fields, sugar cane plantations and pig rearing (major farming activities in Madagascar), and *R. rattus* and *R. norvegicus*, as well as *S. murinus* (a very widespread shrew in Madagascar), are well known reservoirs (Faine 1987). In addition, this disease occurs in the neighbouring island of Reunion.

Intestinal bilharziasis is widespread in humans, especially in the highlands, but has not been reported in rodents (Breuil et al.

1982; Ribot and Coulanges 1982). Yet, recently a *Schistosoma mansoni* adult worm was found in one of ten black rats trapped in the Antananarivo suburbs (E. Sellin, pers. comm.). Larger surveys and more sensitive techniques of detection (work in progress: Ministry of Health/ Institut Pasteur/IRD-ORSTOM) will determine if the black rat is a wild reservoir, as is the case in the West Indies and South America (Rey 1993).

The only known reservoir of rabies in Madagascar is the domesticated dog. No rodent has been found to be a rabies carrier (Ribot and Coulanges 1982).

Until now, no human case of haemorrhagic fever with renal syndrome, due to hantaviruses, has been reported in Madagascar. Since 1985, however, antibodies of hantavirus have been reported in rodents (H. Zeller, pers. comm.). More extensive studies are under way (Institut Pasteur/IRD-ORSTOM) to determine the importance of these viruses in black rat populations trapped in different environments.

RODENT CONTROL IN MADAGASCAR

Organisation of rodent control

Big cities, and the administrative centres of the provinces (with more than 100,000 inhabitants) have a Health Municipal Office, dependent on the mayor. This department is responsible for keeping the town clean, monitoring epidemics and controlling insects and rodents. In the largest cities of the highlands, it is this department that is in charge of plague control. The Health Municipal Office is also in charge of control (by trapping) of plague among rodent

populations in the capital, Antananarivo, and since 1998, in the seaport of Mahajanga.

In small towns and villages, the Department of Communicable Diseases (Ministry of Health) intervenes as soon as human plague cases are reported and organises the control of fleas and rodents in collaboration with the basic health care units.

In rural areas, it is the Department of Plant Protection (Ministry of Agriculture) which leads the farmers in rodent control in the fields and in and around food stores.

Activities of the Department of Plant Protection

After the 1965 outbreak of the plague, rodents were declared a public calamity by the Malagasy state, which meant that the state covered all the expenditure incurred in rodent control. Then in 1976, a division inside the Department was created and dedicated to rodent control. Until the 1980s, this division provided free rodenticides to the farmers, who in turn provided the baits. Zinc phosphide was first used in the seventies and progressively replaced by anticoagulants, mainly chlorophacinone and coumatetralyl. Plant protection technicians determined the abundance of rodents by trapping in different regions and crop types and then, according to the trap success in each particular situation, decided whether to use rodenticides. However, this practice was abandoned due to the deterioration of the economic situation. Nowadays, the farmers are in charge of rodent control with only supervision provided by technicians of the Department of Plant Protection.

In collaboration with GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit—the German Technical Cooperation), the Division of Rodent Control carries out three types of actions:

- ▶ a survey of the population dynamics in experimental stations situated in the different agricultural regions of the country;
- ▶ the promotion of snap-trap use by demonstration in experimental stations and through selling at a low price; and
- ▶ training and communication on health matters, cleanliness and promotion of rat-proofing methods.

Activities of the Division of Communicable Diseases

This division is responsible for the national program of plague control and hence rodent control. The agency supports the local health structures during epidemics and usually provides some training and information.

In collaboration with the municipal health office, a survey of the prevalence of plague in rat populations has been set up in the two most important urban foci: Antananarivo and Mahajanga. This division has distributed two thousand live-traps to the health centres located in the plague endemic zones. These traps are for use in epidemics, and thus promote this type of rodent control.

The aim of these training and information campaigns is to improve the hygiene within habitations. Information posters written in Malagasy on the plague—also highlighting rodent control methods in plague foci—are posted in all health centres within the plague

areas. A technical guide, which is regularly updated and includes rodent control methods, is given to all the doctors working in the plague endemic zones (Division de la peste 1990).

The particularities of rodent control in plague foci

The control of rodent populations in plague foci must follow certain rules. One must always remember that the main problem is not the rodent itself but the fleas. To avoid proliferation of the disease, it is imperative to kill the flea before killing the rodent. During the plague season, rat poisoning must not be done without prior insect control. Live-traps are better than snap-traps, because the latter encourages the dispersion of the fleas immediately after the rodent's death. For the same reason, in the case of chemical control, one must not use acute rodenticides but anticoagulants that work only after a few days, thus giving time for an insecticide to kill the fleas before the rodent dies. Until now, anticoagulants have been little used in Madagascar, so no resistance problems have been reported. However, resistance to insecticides is multifaceted and very widespread in fleas (Ratovonjato et al. 1998). The annual use of preventive insect controls in some cities is mainly responsible for this situation and has had to be abandoned. In rural areas, the problem is also encountered due to resistance to the insecticide DDT, which has been used extensively for malaria control. All these factors indicate the need for a regular survey of the efficiency of the different insecticides and for a rotation in the use of these products.

Improving rodent control

As described above, until recently, few studies of black rats had been performed. Rodent control in Madagascar took place when damage was significant but rarely took into account knowledge of the biology of the black rat. Since the beginning of the 1990s, with the creation of a national program of plague control by the Ministry of Health and the project "Promoting integrated protection of crops and stored foods" by GTZ and the Department of Plant Protection, new studies have begun with the aim of improving rodent control.

Since 1993, twelve monitoring stations have been established throughout the national territory by the Department of Plant Protection. For various reasons, only eight stations have operated correctly to provide reproductive data and two have monitored abundance. As soon as this program becomes fully efficient, it will provide useful data which will enable an adequate control schedule for each region to be established. Two long-term studies of the black rat are being undertaken on the east and north-west coasts and these will provide important additions to our knowledge of population dynamics, which today, is restricted to the central part of the island.

Concerning plague control in the highlands, the monthly survey carried out over the past two years already allows us to propose that rodent control should be focused on a particular area and season. We have demonstrated that sisal fences are the most important refuge area for rodents, fleas and plague. According to the maximum annual abundance of rats and fleas and taking into account the agricultural

activities, we consider that the best time to practice rodent control is in May–June. Human sero-positive results against *Y. pestis* are more numerous in houses located at the edges of the villages, where sisal fences are more abundant and in houses where food is stored in bedrooms. This clearly shows that it is necessary to break the close rodent–man contact and this could be achieved by developing rat-proof buildings.

CONCLUSIONS: NEEDS AND PERSPECTIVES

In Madagascar, the major public health problem linked to rodents is the plague. The most important reservoir is the black rat, which is also the most important pest in the fields and food stores. Along with the economic difficulties in Madagascar, rodent control is extremely difficult because it is the only country in which the black rat has displayed such successful colonisation in all habitats. In spite of the recent progress in our knowledge of the population dynamics of the black rat, there are still important gaps in their population ecology which must be filled before our fight against these rodents becomes efficient and effective. It is necessary to obtain reliable data on the population flow between habitats, due to, for example, the flooding of rice fields in the valleys and the slash-and-burn practices on the hills and at the edges of the forests. Also, we do not have enough long-term studies on the population dynamics in cultivated areas.

More needs to be done with respect to information transfer and training. For example, some rat-proofing methods are well known to farmers, but often they are poorly implemented and inefficient. In rural

areas, better coordination of the activities of the health services and the plant protection services is necessary.

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