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Breeding ecology of the rice field rat (*Rattus argentiventer* Rob & Kloss, 1916) in irrigated rice ecosystem in Indonesia

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Breeding Ecology of the Rice Field Rat (*Rattus argentiventer* Rob & Kloss, 1916) in Irrigated Rice Ecosystem in Indonesia

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Abstract. Rice field rat (*Rattus argentiventer*) as one of the most important pest is the main factor causing the largest yield loss and damage of Indonesian rice crops. The average of rice field damage reaches 161 000 ha, annually. Moreover, rats have also been known as a vector for some zoonoses in humans and infectious diseases in livestock. Most farmers usually practice inappropriate methods to reduce the impacts of the rice field rat attack and rely heavily on chemicals, causing risks to non-target species and the environment. The success of rat control is determined by a good understanding of its ecology. In lowland irrigated ecosystem, the rice field rat commences their breeding during the generative stage and terminate it at the early fallow season. The majority of male rats reach their sexual maturity at the booting stage whereas the females start to give birth at the early generative stage. They perform three times of birth with the average litter size is around 10 for every single rice cropping season. The highest number of embryos is observed at the first birth and getting lower at the second and the third pregnancy, respectively. Most females in the field give birth twice and only a few of them indicate three times of pregnancy. The major factor triggering an increase of rice field rat population density is the availability of food, which lead to the commencement of breeding and subsequent births occur in the generative stage. There is also some ratoon growing during the fallow period which has extended the rat breeding period and affected the population increase.

Keywords: breeding ecology, rice ecosystem, rice field rat

INTRODUCTION

Rice field rat (*Rattus argentiventer* Robinson & Kloss, 1916) attack has been identified as the main constraint for rice crop farming in Indonesia, bringing some damages from light to no yield [1–3]. In Southeast Asia, these damages are estimated at between 5 % to 10 %, annually [4]. Additionally, rat damage area in Indonesia during the last five year period (2011 to 2015) reach 161 000 ha [5]. The damage equals to 620 000 t of rice which actually could support consumption needs of 6 000 000 people within a year.

The rice field rat distributes very broadly as they are able to adapt to a diverse agro-ecosystem such as lowland irrigated, upland, and swampy area. This species has been categorized as an important pest across some commodities such as food crop, horticulture, and estate crop. However, they dominate the rice crop as the main pest in lowland irrigated agro-ecosystem [6, 7]. Additionally, the rice field rats consume plant and animal materials which grouping them as omnivores. This pest has also been identified as a reservoir for some zoonoses found in human and other mammals [8–18].

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Generally, rat attacks occur all over a period of rice cropping from seedling to harvesting stage which continues to post-harvest process in the storehouse. These attacks will be even getting worse in an intensified rice cropping area which does not implement a synchronous planting time and an intensive rat control program [1, 7]. The intensification of rice farming which performs a triple crop within a year and asynchronous planting provide continual cropping which leads to perpetual breeding of this pest all over the cropping season [19–21]. This situation could impact on multiplication of rat population quickly generating a yield loss at the end of cropping season.

Basically, rat control is an effort to suppress their population at the minimum number through implementing various methods and procedures. A particular approach based on integrated rat management has been recommended for rat control program [1, 22]. The integrated rat management has been generated based on a comprehensive understanding of its population dynamics in lowland irrigated agro-ecosystem [6]. Information on their breeding is the most important factor in studying its population dynamics. A good understanding of their breeding ecology could be used as a guidance for rat control program.

The implementation of several rat control methods based on ecological approach have been documented in lowland irrigated ecosystem. By implementing TBS (trap barrier system) which encloses a trap crop planted 3 wk earlier from the adjacent area as a lure crop for the rats, *bubu* traps, and plastic fence, the surrounding rice crops are protected from rat attacks [23–28]. A TBS of minimum size 20 m × 20 m is recommended to be implemented for every 10 ha of rice crop [29]. A similar unit is also effective for protecting nursery at the beginning of planting season when the rice field rats are in breeding season [30]. As the TBS has already been implemented at farmers' level, there was some feedback from their experience. The farmers thought that the TBS is effective to control rat population and protect the crop. However, this technology is costly for them to accommodate in every single cropping season. To respond to their inputs then the TBS was modified to become an LTBS (linear trap barrier system) which consists of plastic fence and *bubu* traps, without trap crop. The strengths of the LTBS is more removable, cheaper, and simpler as it does not depend on the water schedule and planting date of surrounding area. A previous study has demonstrated that the LTBS is effective to reduce rat population between two different large cropping areas with different planting date by anticipating them to migrate [31]. Another study using the LTBS also depicted that this technology can manipulate the rice field rat movement which in turn can figure out their breeding ecology and their population dynamics [7].

HABITAT PREFERENCE OF THE RICE FIELD RAT FOR THEIR BREEDING PURPOSE

The rice field rat represents a nocturnal animal which is less active and hiding in the shade or stays in their burrows in the midday. Moreover, a study on its movement using radio tracking method indicated that these species stay around in adjacent area beyond the rice crop. Conversely, they are much more active and visit rice crop more frequently (60 %) in the night compared to other habitats in surrounding area. A similar study also reported that 82 % of them stay in the dike during the day and more active (95 %) in the rice crop during the night time [32].

Habitat plays an important role in supporting the breeding of the rice field rat. The presence of an adequate habitat would be a benefit for this species as a hiding place to breed optimally. A study on habitat preference of the rice field rat has indicated that there are some requirements for selecting their habitats such as close to the source of food and water and also a safe place for protecting them from their predators and flooding. Then they build burrows that function as a chamber for raising their pups and gathering food, would becoming bigger and complex as they start breeding. Therefore, a good understanding of rice field rat habitat in lowland irrigated area is an important issue for managing their population.

Rat burrow structure at the vegetative stage is still simple, shallow, and short without a dendritic pattern inside. Since the rice crop gets into the generative stage, the construction of rat burrow becoming more complex with more than one exit. At this moment the adult female is preparing herself for delivering their pups. The length and depth of rat burrow during generative stage is double as compared to the one in vegetative stage. The average of rat burrow

length and rat burrow depth are 4 m and 10.3 m, respectively. This such construction is required for widening their burrow to raise their pups [1].

There is a variation in the frequency of a burrow occupied by a rat; it strongly depends on the environment condition. The rats will be leaving their burrow if there is flooding or not enough food available in surrounding area. Usually, only a few of rat still stay in the burrow during the fallow period until planting time. At this period, they migrate to villages and will be back to their previous habitats prior to the generative stage of rice crop. The irrigation channel bank is the preferable habitat for the rice field rats during the breeding season. This due to the surface level is above the water table, then the water does not reach the burrow when flooding occurs. Majority of the large banks were 1 m to 2 m wide and 1 m high. Furthermore, this habitat provides more alternative foods such as crustaceans, insects, and grass seeds, and ready access to water during the fallow season [3].

There is a tendency for multiplication of the number of rice field rat burrow during generative stage as 5.6 times much higher than at vegetative stage in a 100 ha area located in Brebes, Central Java. The situation of the surrounding environment is the main factor determining the habitat preference of the rice field rats in lowland irrigated area [1]. Based on rat captured from five various habitats in lowland irrigated area, irrigation banks and village border are the preferred habitats. The highest number of rat captured comes from the village border (35.1 %), followed by the rat captured from the irrigation banks (29.8 %), paddy's road (16.5 %), rice canal (9.6 %), and dike (9.0 %) [1]. A study on habitat use in Sukamandi, Subang (West Java) also depicted that irrigation channel banks and village are the main habitats in lowland irrigated area. There are only a few rats occupy the road bank habitat, probably due to the human activity much more intensive in this habitat [3].

A similar study on habitat preference also indicated that they select irrigation channel bank as the main habitat for their breeding purpose. The highest number of breeding females (pregnant and lactated) found in irrigation channel bank (40.9 %), followed by village (22.6 %), paddy's road (20 %), paddy's canal (10.7 %), and paddy's dike (3.8 %) (Fig. 1). Based on their breeding purpose, the rice field rats select its habitat for some reasons. They search for a specific location which could protect their pups from flooding or predators. Therefore, an irrigation channel bank which has more than 1 m height and width is the most acceptable place for building their burrows. This kind of habitat is the best place for the breeding females to raise their pups since the burrow structure is much longer and more complex with a dendritic pattern [19].

Although the village is the preferred habitat for the rice field rats during the fallow period, there is only 22.6 % of breeding females occupy this habitat [33]. A similar pattern was also found in paddy's road habitat, which only 20 % of breeding females stay in this habitat. It seems that due to the farmers used this habitat for their activity more frequently than this situation is supposed to be the main cause for the rats not to breed in the habitat as they do not feel safe from predators including human. A habitat with less than 0.5 m widths such as paddy's canal and dike is not the favorite place for the rats to breed.

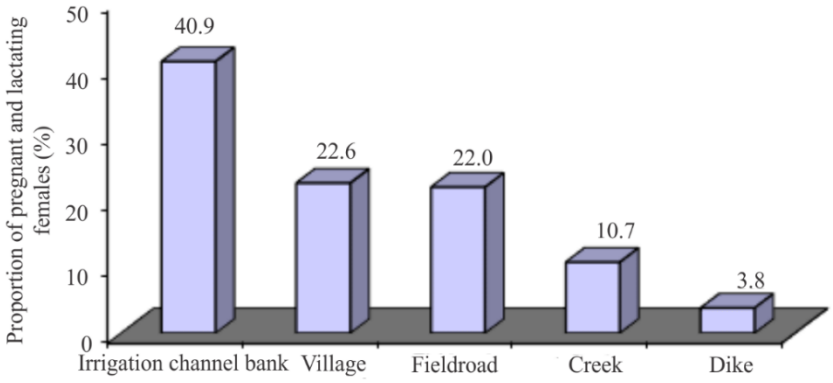

FIGURE 1. Proportion of breeding females in various habitats sampled from lowland irrigated area [19]

SEXUAL MATURITY OF THE RICE FIELD RATS

The rice field rats are able to breed since they get into their sexual maturity. Female maturity has been identified based on their vaginal opening followed by estrous cycles and ovulation which usually started at 28 day old. This usually occurs when the females reach around 31 g to 40 g on their body weight and will get the first pregnancy at 40 d old with a body weight around 60 g to 120 g. An observation for female breeding can also be performed from their teat and vaginal class [34]. An estrous cycle is initiated by an irregular cycle which followed by a regular cycle period which lasts for 4 d to 5 d. The regular estrous cycle will continue until the individual reach (10 to 12) months old [35]. Almost 100 % of female captured from the generative stage of rice crop have given birth (Fig. 2). This reflects that the females which alive at the generative stage have already started their breeding and categorized as adult females [6].

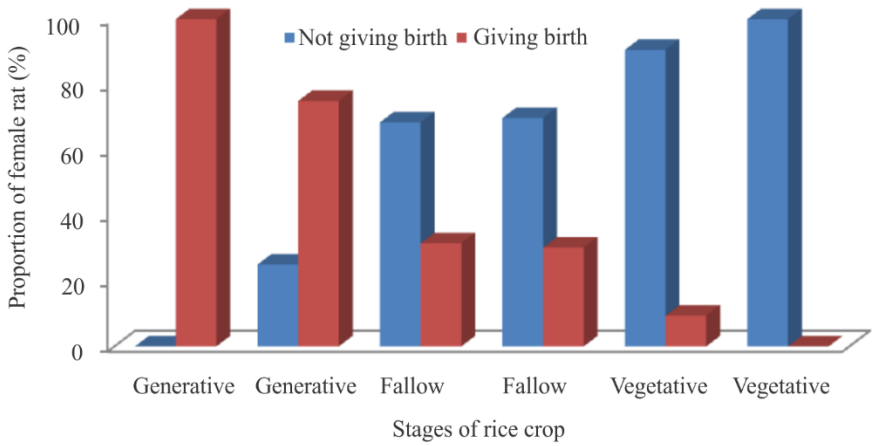

FIGURE 2. Proportion of adult females which giving birth and not giving birth at various rice stages sampled from lowland irrigated area [6]

Sexual maturity of males is determined by the development of testes. The testes of a mature male are getting bigger with sperm inside inserted in the scrotal sac. On the other hand, an immature male still has smaller testes and located in abdominal which then called abdominal testes. The males require 60 d for getting into sexual maturity with their body weight reach around more than 90 g. A study indicated that the growth of male sexual maturity correlates with rice crop stage. The peak of male sexual maturity growth coincides with the period of rice crop stage between maximum tillering and early generative stage. Almost 100 % of males during this period have already reached their sexual maturity. This indicates that all males are ready to mate with mature females and start to breed. The population of juvenile males and males with abdominal testes is getting higher at the late of the generative stage and fallow period (Figure 3) [6].

At the end of the generative stage, fallow until tillering stage of the next cropping, the population was dominated by young female rats which have not ever given birth yet. They consist of immature females or mature females which never given birth before. The highest population of immature females occurs in the fallow period, and these females are born from the previous generative stage. The beginning of rice field rat mating is expected to commence at maximum tillering or primordial since either the males have already matured sexually, or the pregnant females are also found during the generative stage of rice crop. Additionally, at the maximum tillering, the rice canopy has already fully grown which serves as a good hiding place for the rice field rats from the predators and do mating.

The rice field rats are predicted to be able to response environment very well especially for the growth of rice crops which is recognized as their main food. Such studies indicated that among several foods available in the environment, booting rice stem is the most favorite food for the rats [36, 37]. It was predicted that high proportion of gibberellin found in booting rice is the trigger for the sexual maturity growth of rice field rats. However, there is no study to

answer this hypothesis yet. Several studies revealed that breeding cycles in rodent are initiated by the availability of food in the environment especially an early generative crop stage which triggering sexual maturity for male rats. The rice field rats would response the presence of the generative stage of rice crop by starting their breeding [38–40]. Separate research reported that there are 54 volatile compounds extracted from booting and milky stages which have been identified as the favorite food of rice field rats. These compounds have dominant aromas such as green, sweet, fat, buttery, creamy, fruity, pungent sour, and beany [41].

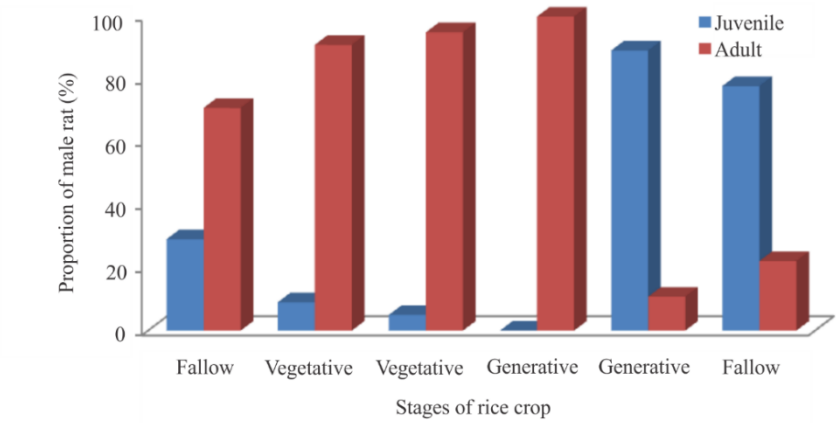

FIGURE 3. Proportion of juvenile and adult males with abdominal and scrotal testis in various rice crop stages in lowland irrigated area [6]

FREQUENCY OF THE RICE FIELD RATS FOR GIVING BIRTH

Number of Pups

Breeding is the most important factor determining the growth of rice field rat population. Their breeding strongly correlated with the quality and quantity of food available in the environment. Although the rice field rats are classified as an omnivore, rice crop is still the most favorite food [37]. A study indicated that there is a strong influence of rice booting consumed by rats to their breeding performance [40]. Their reproduction was started during this period and the newborn generation led to a multiplication of population for the next cropping stages. There are two times of rat breeding in an area with two rice plantings within a year. A different situation was recorded that there is an irregular rat breeding in an unsynchronized planting area. The rice field rats will breed continually if the generative stage of rice crop is available along the planting season [1].

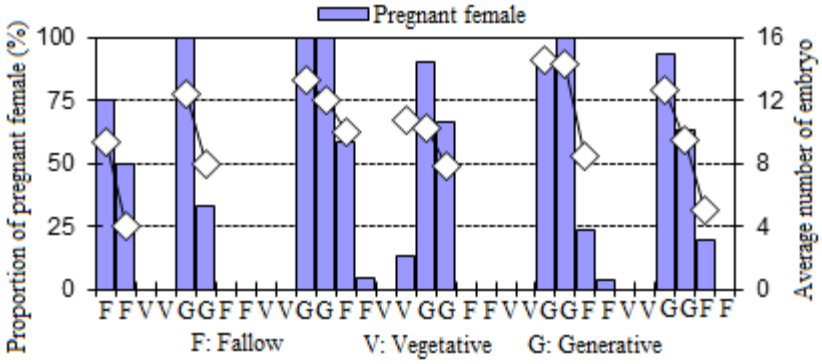

FIGURE 4. Proportion of pregnant females and the number of embryos produced during a pregnancy period at the various rice stages in lowland irrigated ecosystem with rice-rice-fallow cropping pattern [19]

Generally, rodents including rice field rats have a fast breeding potential which leads to quick population growth. An adult female requires 21 d for her pregnancy and 21 d for a weaning period. The females are able to pregnant and wean in the same period. They will mate again in 48 h after giving birth. In a good environment, a rat burrow will be occupied by a pregnant female with two pup generations [1, 19].

Frequency of the Rice Field Rats for Delivering Pups

Frequency of female rice field rats delivering pups can be identified based on the number of placental scars. The placental scars are the remaining spots where embryos implant along the uterus performed as reddish, brownish, until black color dots. Based on an autopsy of 164 adult females have delivered pups, there were 54.27 % of them with one set of placenta scar, 34.76 % have delivered twice, 10.36 % have delivered three times, and 0.60 % have delivered four times, respectively. This means that the frequency of those females has delivered pups as many as the sets of placental scars [19, 42]. Although those females have an ability to deliver pups four times along their live, there were rarely new generations produced from the adult females with more than one y old (Table 1).

TABLE 1. Proportion of placental scars from autopsied females have delivered pups in lowland irrigated ecosystem [19].

Number of adult females sample	Number of placental scars set (frequency of giving birth)	Proportion of females with placental scars set (%)
89	1	54.27
57	2	34.76
17	3	10.36
1	4	0.60
164		100

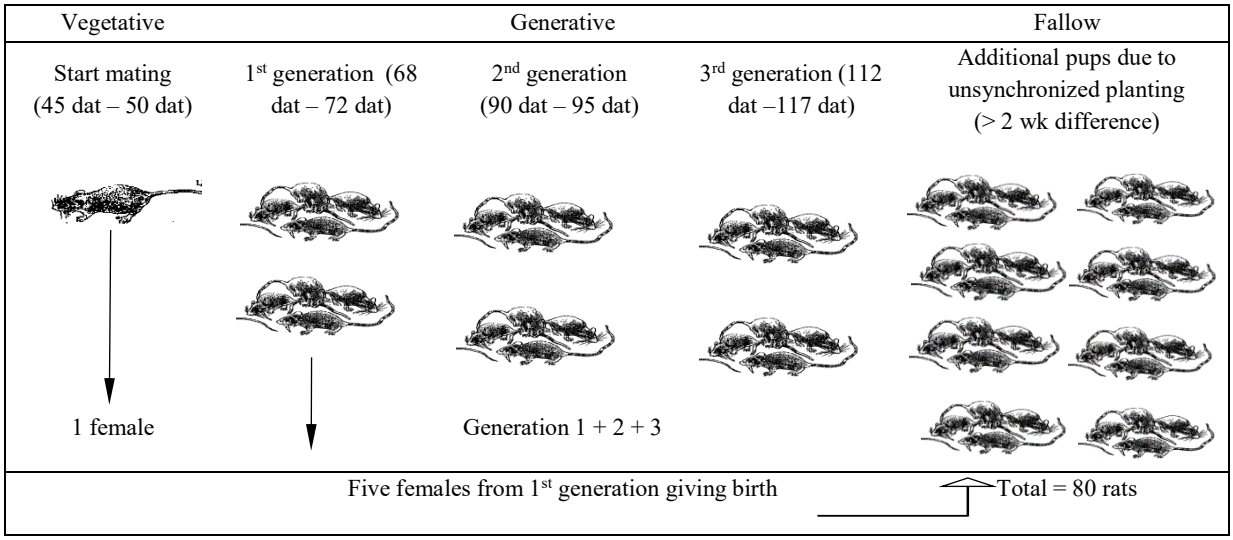

FIGURE 5. Estimated number of pups delivered from one female within a rice cropping season [19].
dat = day after transplanting

The rice field rats commence their mating at the maximum tillering stage in an area planted with new rice variety plant type with age around 120 d. The females required 21 d for their pregnancy and were able to re-mating 48 h after delivered pups (postpartum estrous). Therefore, the potential of adult females for giving birth within a rice cropping season was three times. The average of litter size delivered by an adult female was 10 pups with equal sex proportion. This condition produced around 30 pups during a planting season. If the cropping system were unsynchronized with more than 2 wk period difference, there would be a lot of ratoon available during the fallow period. These ratoons

then were used for the first young generation for supporting their physical development and breeding. Additionally, the first generation of young female was ready for delivering their pups. The first five young females delivered a total of 50 pups which then accumulated with the previous 30 rats to become 80 young rats (Fig. 5) [19].

IMPLICATION FOR RAT CONTROL

Population size is generated from several processes, not only mortality but also natality, immigration, and emigration [3]. Immigration and birth are the two main factors affecting increases in rat population. Immigration is identified as the most important factor triggering fluctuations in a rat population [40]. As an r-strategist animal, the rice field rats are able to breed in a short period and their population will increase quickly which sometimes lead to an outbreak. Occasionally, the outbreak occurs when the food available abundantly supported with such good habitats and hiding place. When the population with high density has been formed, there will be a competition which leads to a decrease in food availability and hiding place, which in turn causing a population decrease naturally.

Rat control has been conducted through an approach on understanding of their ecology. This program has been known as an integrated ecologically based rodent management [1, 22, 31]. Their breeding is the most important aspect has to be understood as a basic guideline for conducting control programs. Based on a study [19], it has been known that population of rice field rat grow very fast. Their breeding season occurs during the generative stage of rice crop. Therefore, a strategy could be performed for controlling them through decreasing of their population as early as possible. This could be done at the fallow season and land preparation, for anticipating them from continuing their breeding at the generative stage of rice crop. Killing one adult female at the beginning of planting season equals to kill 80 rats which are an estimation of population accumulation born from one reproductive female within a cropping season. Additionally, by implementing rat control strategy prior to planting season is the best recommendation to suppress their population growth.

The other important recommendations to minimize rice field rat breeding are practicing synchronized planting, using same rice varieties and cropping pattern in a large area comprehensively. Unsynchronized planting leads to a multiplication of rice field rat population due to the availability of generative stage of rice crop could maintain their breeding continually. If this kind of multiplication of population occurs, then it will be a big problem for farmers to control them. Moreover, an intensified cropping system by planting rice crop three times within a planting season has significantly increased the population of rice field rats [21]. Therefore, an intensified rice cropping system is not recommended to implement continually, except in combination with secondary food crop.

In irrigated lowland area, the majority of rice field rats prefer to stay in irrigation channel bank for supporting their breeding. They build a burrow with the special chamber as a preparation for their breeding and raise their pups. The irrigation channel bank has been identified as the main habitat for the rice field rat breeding. Therefore, it is strongly recommended to do fumigation with sulfuric smoke in this habitat during the generative stage of rice crop. The fumigation could be combined with digging the rat burrows to ensure that the pups are also affected by the fumigant. Sanitation of weeds growing along the irrigation channel bank is another recommendation to minimize their breeding. Doing this sanitation means that we do not provide a good habitat anymore for them to protect themselves and hide from their predators.

The recommendation on rat control has been implemented in several areas based on the adaptive research conducted in Cilamaya, West Java. These recommendations have been validated and verified at the village level in a large area of 80 ha to 120 ha using an ecological approach to rodent pest management [22, 27]. However, there are still some rat problems documented among provinces around Indonesia. For example, a significant yield lost (> 20 %) is reported on a large scale from 1977 to 1978 with 450 000 ha damaged area by rats. Another case occurred in 1997 to 1998 with more than 200 000 ha rice crop was attacked by this pest. Furthermore, the most severe losses to rice crop caused by rats occurred in West Java in 2008 with high losses documented on 134 814 of rice crops. The second level of the highest damage by rats was reported in Central Java in 2008, where 83 735 ha of rice suffered high damage [43]. These rodent problems represent chronic and seasonal damage which occur in a large area in specific years and referred to as an outbreak.

The outbreak of rodent population and subsequent high damage have been influenced by a range of factors. The first factor is unusual climatic events which led to droughts causing asynchronous planting. An example of this situation is the 1997 to 1998, *El Nino* which triggered to a rodent population outbreak. This outbreak appeared to be correlated to the staggered planting of the rice crops during the 1997 to 1998 wet season. The staggered planting led to an asynchronous planting of the rice crops in the adjacent area and extend the breeding season of the rice field rat which in turn generated a population outbreak. The second factor is unusual rainfall which was represented in 2000 to 2001 wet season crop. As the harvesting time was followed by unseasonal heavy rain, this prevented farmers from doing a land preparation. The situation led to the growth of a ratoon rice crop causing the survival and breeding of the rice field rats extend and multiply the rat population densities for the next season. An occasional flood is also the other main factors causing the rodent outbreak. This flooding led to a massive rat migration to the next village, which was identified as the source of the rat population. An example of this occasional flood was occurred in Citarik village, Karawang, West Java, in 2007. Increased cropping intensity is also the other factor which influenced a rodent outbreak. For example, is the Indonesian government program to respond a reduction in rice production as the 1997 to 1998 *El Nino* event. The government designed to increase rice cropping intensity in some areas to become three crops a year (*IP padi 300 programs*). However, this program extended the availability of high-quality food and compressed fallow period triggered by an increase in rat population which in turn causing rodent outbreak. The last main factor causing rodent outbreak is an asynchronous planting by more than 2 wk due to the complexity of the farming system within a large area. Differences of water schedules in adjoining croplands and a shortage of labor occur at transplanting were identified as two typical situations lead to the asynchronous planting of rice. An example of the impact of asynchronous planting of rice cropping on rodent population was clearly observed when different planting date were applied on a large national seed farm at Perum Sang Hyang Seri (1 400 ha) and a neighboring farm (400 ha) at the Indonesian Center for Rice Research (ICRR) in Sukamandi, West Java [3]. A previous study reported that a large number of rats migrated to ICRR farm in 1995 to 1997 after the seed farm was fallow period. The differences in planting date between Perum Sang Hyang Seri and ICRR farm maintained the availability of quality food for the rice field rats. This situation extended the rice field rats breeding cycle which in turn increase their population [29].

CONCLUSION

Rice field rat is an r–strategist animal which has a very short breeding cycle leads to a multiplication of their population in a short period. Habitat is identified as one of the main factors supporting their breeding. There are four types of habitats as their hiding place and breeding sites such as irrigation channel bank, village, field road, creek, and dike. However, the irrigation channel bank is the most favorite habitat as their breeding site. The other main factor determining the rice field rat breeding is the availability of the generative stage of rice crop in the field. Based on those breeding characteristics and factors affecting their breeding, strategy on rat controls should be performed by planting synchronously to limit their food source and suppress their breeding. Mass hunting is the next recommendation for controlling rat at the beginning of planting season to reduce the population of breeding females. Fumigation of their burrow is another rat control activity which has to be done during generative stage of rice crop due to they breed during this period.

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