MARK-RECAPTURE METHOD: A NEW DIMENSION IN MANAGING THE RICE BLACK BUG, *Scotinophara sorsogonensis* Barrion et al. (HEMIPTERA: PENTATOMIDAE) IN BICOL REGION, THE PHILIPPINES

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ABSTRACT

A new mark-recapture technique for adult rice black bugs (RBB), *Scotinophara sorsogonensis* Barrion et al. (Hemiptera: Pentatomidae), successfully determined for the first time, the mode of migration, flight dispersal pattern, and distance traveled by RBBs. The water resistant, luminous Aervoe Glo™ paint was placed as small dots on the pronotum and scutellum, each dot representing the specific date of field release during full moon (FM) and non-full moon (NFM) periods. Altogether, 27,000 (13,000 for FM and 14,000 for NFM) RBB adults were marked and released in the farmer's field between 1800 and 1830H in Mabca, Sagñay, Camarines Sur. More RBBs migrated during NFM (5,566) coupled with calm weather. NFM recovery of marked adults was highest (93.8%) in July and lowest (21%) in August, whereas recoveries were only 65% in June and 32% in September for FM period. Catch patterns in order of preponderance were W-N-NW-NW for NFM and SE-N-W-E for FM. Marked bugs traveled short (0.1m-30m) and long (2- >30km) distance modes depending on weather patterns. About 27% of marked RBBs were unaccounted for and presumed to have migrated over long distances beyond monitoring points. Results challenged previous RBB management recommendations and new ones are enumerated. The mark-recapture method applied nocturnally for monitoring RBB migration facilitated identification of species of predators in the field such as earwigs (four), carabids (11), anthicid (one), reduviids (three), and spiders (eight). Further, the generalist *Rhinella marina* (L.) was observed to consume 808-1,214 adult RBBs per predation activity.

Key words: mark-recapture technique, migration, natural enemies, rice black bug, *Scotinophara sorsogonensis*

INTRODUCTION

Insect migration is a paradigm for survival by movement (Taylor & Taylor, 1983; Farrow, 1991) and the persistent search for habitats or agricultural landscapes. It is expected to provide the much required ecological templates for adaptation, reproduction, and survival (Southwood, 1977; CSIRO, 1991; Carson et al., 2004). It is also a key process in the population dynamics of insects, including agricultural pests, that occur regularly and at most times precisely, as manifested by the honey bees (CSIRO, 1991) in tracking resources in time and space (Drake & Gatehouse, 1995). Insect movement as a prelude to migration has been well documented. Most common types of movement are: (1) downwind between the geographically fixed breeding areas influenced by variable wind oscillations, (2) when winds are in appropriate direction (Hughes, 1979; Kennedy & Way, 1979; Taylor & Reling, 1986), and (3) for durations required for specific distances to be travelled (Rogers, 1983). Conversely, Baker (1978) presumed that permanent migratory pathways have evolved relative to fixed geographical relationships required to sustain seasonal breeding, or for food sources. Such preference is termed 'navigation,' treated separately from wind direction movement (Farrow, 1990).

Insect migration has stimulated the minds of many scientists worldwide, exploring its many facets that entail ecological, behavioral, physiological, and genetic bases, and the accumulated knowledge has been comprehensively reviewed (Johnson,1969; Farrow, 1990 for the acridoids; NIAS, 1991 for agricultural pests; Drake & Gatehouse, 1995; Dudley, 1999 for the biomechanics of insect flight). Accordingly, insect migration is a common and widespread phenomenon both geographically and across taxa (Farrow, 1990). To date, some 28 species of insects - 18 Lepidoptera, seven Hemiptera, two Coleoptera, and one Orthoptera, had been documented as long-distance migrants in North America (Drake & Gatehouse, 1995), and only six species in Asia - three Hemiptera, two Lepidoptera, and one Orthoptera. The Philippines contributed three species to the checklist of migrant species, namely: the locust *Locusta migratoria manilensis* Meyen, destructive caterpillar *Mythimna separata* (Walker), and brown planthopper *Nilaparvata lugens* (Stål).

Drake & Gatehouse (1995) outlined a holistic conceptual model of insect migration and proposed 12 salient points. The model improved the existing knowledge on insect migration per se. As a whole, there are also numerous accounts of individual insect migrations, notable of which are within Africa, North America, and Europe for both short- and long-distance migrations related to weather, seasonal changes in climate, and prevailing wind (Pedgley et al.,1995). Much of the work focused on the migratory desert locust and grasshoppers in Africa and moths in North America (Rainey, 1989).

Insect migration in Asia

The occurrence of individual insect migration in Asia is similar to those in North America and Africa but involved dissimilar taxa. In Japan, the migration of the Oriental armyworm, *M. separata*, seriously affected >200 ha of agricultural crops eight times in 31 years within the period 1958-1987 (Oku & Kobayashi, 1977; Hirai, 1988, 1995), and migration of planthoppers and leafhoppers since 1941 on rice had been observed (Hirai, 1995). Migrating populations of armyworm became a problem also in Korea in 1981, 1987, and 1990 (Lee & Uhm, 1995) and in China in 1963 (Li et al., 1964). Radar observations confirmed large scale migration of armyworm moths into China followed by a 1977 outbreak (Yan, 1991).

Other insect pests from rice fields also demonstrated migrations and the role of climate and weather had been linked to this peculiar event in Japan. The three hemipteran (auchenorrhynchan/fulgoromorph) pests of rice involved were the small brown planthopper *Laodelphax striatellus* (Fallen), brown planthopper (BPH) *N. lugens*, and white-backed planthopper (WBPH) *Sogatella furcifera* (Horvath) since the mid-1700 (Suenaga & Nakatsuka, 1958; Kisimoto & Sogawa, 1995). However, the significance of migration in initiating the BPH and WBPH outbreaks was first recognized by Murata & Hirano (1929).

Records of insect migration in the Philippines

The first record of insect migration in the Philippines was during the Spanish era exemplified by the sudden appearance of the migratory locust, *L. m. manilensis*, in huge swarms (termed as "outbreaks"). Since then, no outbreak was reported for a long time until in 1910 when destructive caterpillars in massive numbers attacked upland rice fields in Batangas province (Mackie, 1910). After 26 years, an outbreak of locust and grasshoppers were recorded again, virtually forming a rhythmic pattern reappearing at intervals of 11 years (Uichanco, 1936). The latter surmised that the locust population developed from the Liguasan marshes in Central Mindanao and migrated northward up to Taiwan and eastern China, and down south to Sulawesi, Indonesia. Small regular outbreaks of *L. m. manilensis* occurred after that.

In 1964, there was no reported insect migration, but pest outbreaks occurred in the Philippines consequent of the change in the environment brought about by the introduction of modern high-yielding varieties requiring high agrochemical inputs. Thus, a new insect pest evolved within an experimental farm. The pest build-up was quick and caused an outbreak in the same period at the International Rice Research Institute (IRRI), Laguna, Philippines (Cendaña & Calora, 1964). The insect pest was the BPH that became a threat to rice production not only in the Philippines but the entire tropical Asia between 1964 and 1985. It became the most pre-eminent insect pest of the Green Revolution era (Kenmore et al., 1984) rising from secondary pest status.

Studying insect migration in relation to pest outbreaks

The problem of monitoring insect movement may be approached in various ways, namely: use of radar systems, airborne net traps, suction light traps, yellow pan traps, and mark-and-recapture method. The use of radar facility, airborne traps fixed on land or in passenger boats, and mark-and-recapture techniques, were effectively used in Japan and China in pest surveillance and monitoring insect migration.

In the Philippines, insect migration research is rather passive. Information on the insect pests' mode of migration and dispersal has been very meager, except for the contributions from the IRRI on rice leaffolder moths marked with luminous substance to track down how far the moths can travel (Alinea &

Cohen, 1991) and the works on planthoppers (Rosenberg, 1981; Saxena & Justo,1984). It was not surprising then, that on many occasions where there was a sudden presence of a huge insect population, the report was an outbreak of a migrant pest. This was well exemplified by case of the Rice Black Bug (RBB), *Scotinophara coarctata* (Fabricius), reported to have migrated from Palawan to Curuan, Zamboanga City, Mindanao in June 1992, then to the Autonomous Region of Muslim Mindanao in March 1995, North Cotabato in 1996, the Visayas in 1998, and Bicol Region, Luzon Island in late 2005 (PhilRice, 1995), without conducting any reliable technique for identification and determining the real status of the insect(s) involved. Systematic studies revealed that multiple species of RBBs are present in Philippine rice fields, and thus, also confirmed that *S. coarctata* is restricted to Palawan. Hence, the previous thinking that *S. coarctata* had been invading other islands was simply a myth and misconception. However, initial observations showed that RBBs might exhibit short distance migration.

This study aimed to: (1) elucidate the bio-ecology of the RBB, *S. sorsogonensis* Barrion et al.; (2) evaluate the applicability of the mark-and-recapture method in determining the migration and dispersal mode of RBB in the Bicol Region; and (3) develop recommendation(s) that may help farmers mitigate the RBB population build-up in the field without using chemical pesticides.

MATERIALS AND METHODS

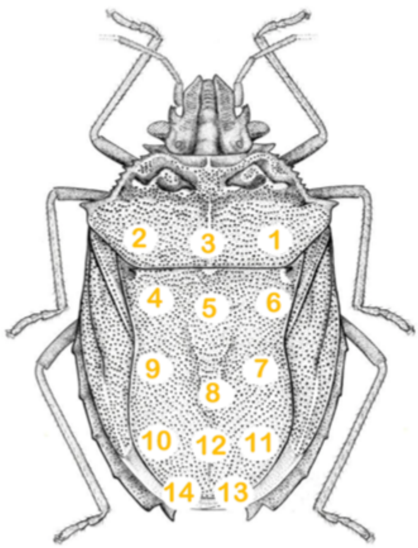
Stock culture

Periodic collecting of live specimens of all developmental stages (egg masses, nymphs, and adults) of RBB was done in 11 sites in Sorsogon (Gubat, Bulan, Rizal, Prieto Diaz, and Matnog), 11 in Albay (Legazpi, Rawis, Navas, Tabaco, Tiwi, and Malinao), and three in Camarines Sur (Sangay and Tigaon) to assure regular monthly supply of at least 5,000-7,000 adults of RBBs which were needed for the mark-and-recapture method releases during non-full moon (NFM) and full moon (FM) periods from June to December 2009.

All field-collected bugs were brought to the Rice Black Bug Laboratory (RBB Lab) at the Central Bicol State University of Agriculture, Pili, Camarines Sur for maintenance rearing. The bugs were reared on two types of cages, namely: 15.5 x 14 x 30 cm PET bottles and 30 x 30 x 32.5 cm paint jars, provided with cleaned rice stubbles treated with 0.01% commercial sodium hypochlorite solution to minimize fungal infection of the stock culture. Each jar maintained a colony of 200-500 adults.

Marking and release

RBB adults were quite agile and avoided open air with too much light. Before marking, bugs were collected from rearing jars and placed in clean plastic jars without stubbles but covered with nylon mesh tops. Each jar was sprayed with CO_2 for 1-2 mins to anesthesize the bugs and prepare the set for marking the prothorax and scutellum based on the developed marking system (DMS) (Figure 1). Immobilized bugs were then positioned dorsal side-up on a sheet of



R1 =right pronotum; 1st release, June 8-10
R2 =left pronotum; 2nd release, June 19-21
R3 =mid pronotum; 3rd release, July 7-9
R4 =basal left scutellum; 4th release, July 23-25
R5 =mid basal scutellum; 5th release, August 6-8
R6 =basal right scutellum; 6th release, August 25-27
R7 =right subanterior scutellum; 7th release, Sep. 5-7
R8 =midsubanterior scutellum;8th release, Sep.14-16
R9 =left subanterior scutellum; 9th release, Oct. 4-6
R10=left anterior scutellum; 10th release, Oct. 18-20
R11=right anterior scutellum; 11th release, Nov. 3-5
R12=midanterior scutellum; 12th release, Nov. 13-15
R13=right anterior scutellum, 13th release, Dec. 2-4
R14=left anterior scutellum, 14th release, Dec. 13-15

Figure 1. The designated marking standard adopted for the adult rice black bug migration during full moon (odd numbers) and non-full moon (even numbers) release periods.

tissue paper and individually marked with a water-resistant, luminous Aervoe Glo™ orange paint. Each dot position represented the specific date of its field release, either for the non-full moon (NFM) or full moon (FM) period. Marked bugs were allowed to recover for at least an hour before exposing them in the release site.

Field releases were conducted regularly between 1800 and 1830H in the selected site in Mabca, Sangay, Camarines Sur Province. A 45 x 45 cm platform was set-up one meter above the ground to hold all the marked bugs for migration monitoring. Release of marked bugs was completed in 3-5 mins.

Monitoring process

Annuli based on true N with eight directional sampling points, namely: N, S, E, W, NE, NW, SE, and SW at intervals of 0 (release point), 1.0, 3.0, 5.0, 10, 20, 30, 50, 100m, 1.0 km up to 2.0 km were established.

Two hours after release, the movement/dispersal modes of the bugs were monitored, counted, and recorded by at least four field workers. Each person was assigned two adjacent sampling directional points, i.e., N & NE, N & NW, S & SE, and S & SW, to speed up monitoring. The process usually ended at around 2300-2330H but was continued the next day until completed. The process was done twice a month to cover the NFM and FM releases. Figure 1 served as the main reference guide in the field monitoring of migrant RBBs.

Data Analysis

The Biodiversity program (bdp) was used to analyze: (1) abundance of migrants, (2) distribution (aggregated vs. discordant) of the recaptured RBBs in the field, (3) diversity of recaptured based on monthly recovery of marked individuals, and (4) to determine the similarity (%) of RBB migrations over the 7-month period (June-December 2009) under two climatic conditions, viz., dry (DS) vs. wet season (WS).

RESULTS AND DISCUSSION

Mark-recapture method

Fourteen releases were completed in seven months for both FM and NFM from June to December 2009 exposing some 27,000 marked adult RBBs - 13,000 for FM and 14,000 for NFM. The mark-recapture method confirmed for the first time that RBBs are migrant insects capable of short and moderately long-distance migration. The most important breakthrough was the discovery of migration even during non-full moon periods, a complete contrast to the conventional knowledge that migration happens only during bright and clear full moon. Therefore, migration and colonization of crops by RBBs in the past may simultaneously be happening in the absence of the waxed lunar phase. Thus, a new strategy has to be developed to mitigate RBB spread in the Bicol Region.

Percent recovery of marked and released RBBs

Of the total exposed, only 37.04% (10,000 RBB) were recovered with 4,434 (16.42%) taken during FM and 5,566 (20.61%) at NFM (Figure 2). The rest of the marked bugs—17,000 (62.96%) were either left at the base of the release board and unable to fly (1,816, 10.68%), exposed to predation (1,148, 6.75%), or they completed both short and medium-distance migration (14,036, 82.56%). Of the successful migrants, 6,725 (51.73%) were from FM release while 7,311 (52.22%) were from NFM release. Figure 3 compares the number of recaptured RBBs every month based on FM and NFM releases. Apparently, RBBs were migrating more actively during NFM than during FM time although the difference was not significant.

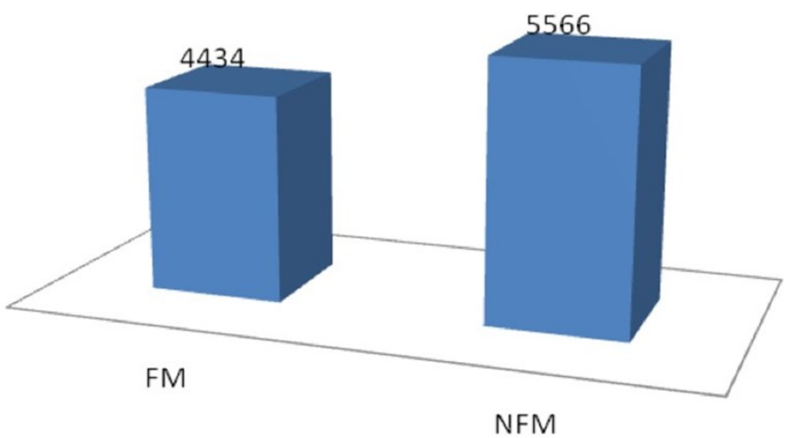


Figure 2. Total catches of marked rice black bugs over a 7-month period of releases made during full moon (FM) and non-full moon (NFM) periods. Mabca, Sangay, Camarines Sur. June-December 2009.

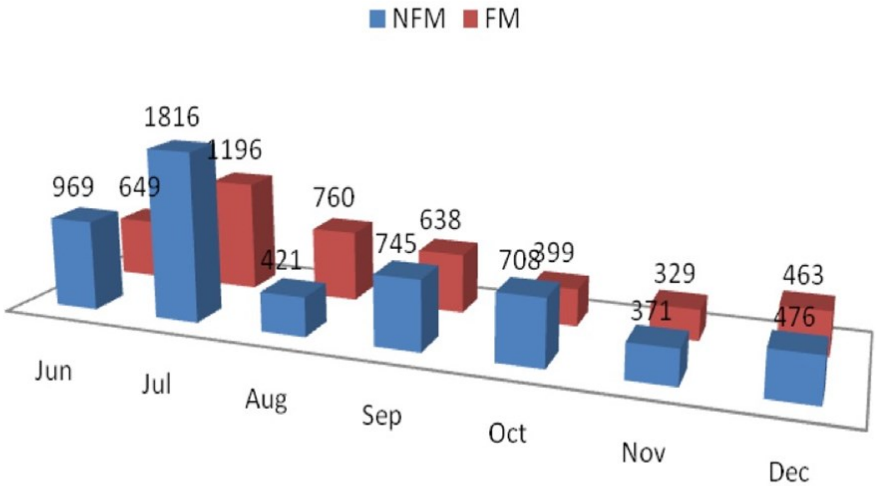


Figure 3. Monthly recaptures of rice black bugs over a 7-month period of releases made during full moon (FM) & non-full moon (NFM) periods.

Non-full moon releases

At NFM, the total number of recaptured RBBs totaled 5,566 marked individuals, representing only 39.76% of the total released per lunar phase category and 20.65% of combined FM and NFM releases. The mark-recapture method was most effective in the late dry to the early wet season. The catch trend in decreasing order was noted in July (1,876 individuals) > June (961) > September (551) > October (354) > November (297) > December (276) > August (120) (Figure 4).

The dispersion of recaptured RBBs was aggregated (X^2=4,410.29, df=56; pooled value=3,538.605, df=6) and heterogeneity was discordant (X^2=871.68, df=50). On the other hand, diversity (H^1) of recaptured individuals during NFM releases ranged from 1.715 to 1.995. The pattern of H^1 in decreasing order was: July (1.995) > November (1.900) > June (1.891) > October (1.874) > December (1.792) > August = September (1.715) (Figure 5). The number of recaptured individuals was relatively even with J^1 values of 0.825-0.959 (Table 1).

Results of monthly recapture of marked RBB during NFM showed two clusters based on Jaccard's single-link cluster analysis. Of the seven months, the August recapture had the lowest catch forming one cluster, but the nearly similar catches recorded in June, July, September, October, November, and December put them together as a separate group. The coefficient of similarity between the two clusters was 74.81% (Figure 6). The dispersing marked RBBs were short-distance migrants at the start of exposure during NFM periods. Approximately 84.09% were retrieved 1.0 m away from the release point barely two hours after release, 8.6% at 3.0 m, 1.24% at 5.0 m and 1.24% also at 0.25 m. However, the pattern changed afterward as 7,311 (52.22%) marked individuals were all gone 36 hrs later. This suggests that RBB acclimated first with the environmental conditions and took off when the proper conditions for migration were ready. Otherwise, the marked RBBs could have been collected by

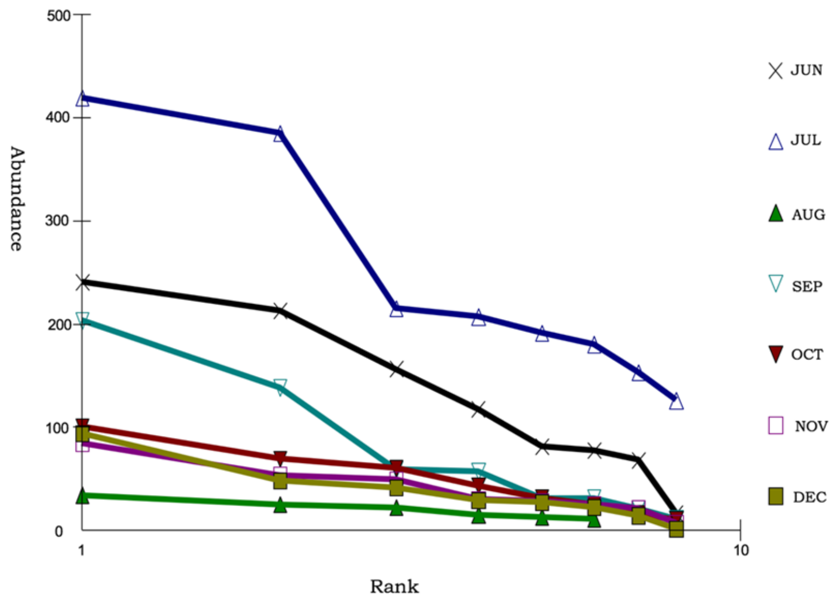


Figure 4. Rank abundance curve of recaptured rice black bugs during the non-full moon release periods. Mabca, Sangay, Camarines Sur.

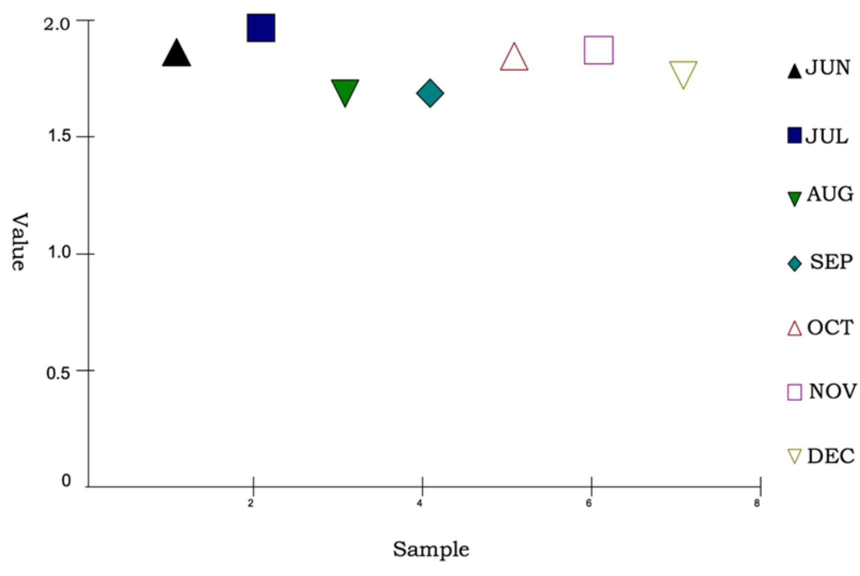


Figure 5. Diversity of recaptured rice black bugs based on individual monthly catches during non-full moon release periods.

Table 1. Shannon's diversity values (H^1) and evenness (J^1) based on a number of monthly recaptured individuals of rice black bugs during on full moon release periods. Mabca, Sangay, Camarines Sur.

Indices	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H^1	1.891	1.995	1.715	1.715	1.874	1.900	1.792
J^1	0.910	0.959	0.957	0.825	0.901	0.914	0.862

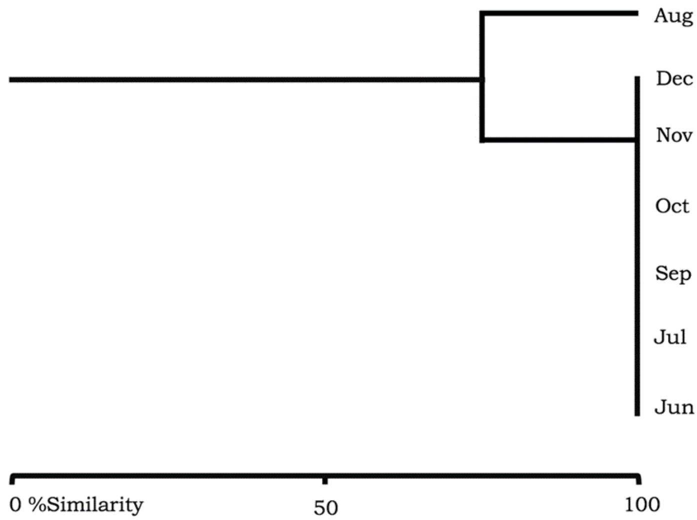


Figure 6. Similarity of population catches of non-full moon recaptured black bugs based on Jaccard cluster analysis.

then. Thus, *S. sorsogonensis* followed concepts postulated by Kennedy (1961) which stated that migration is actively initiated, maintained, and terminated; an active process and not accidental in nature; as well as those by Kennedy (1986) and Gatehouse (1995) that the migrant is essentially unresponsive to stimuli associated with favorable habitats, but this initial phase of migration is terminated spontaneously and followed by flight with the migrant in responsive mode (Drake & Gatehouse, 1995). The initial NFM dispersion of marked RBBs had three distinct peaks, namely: July (1,843 individuals) > June (792) > September (521) (Figure 7).

Based on eight directionally fixed monitoring points or the annuli mentioned earlier, RBB demonstrated variations in migration pattern and distribution. In general, dispersion of RBBs was slow but always formed aggregated occurrence at every landing arena. So far, only 12 individuals were collected 10 m or more from their release point at NFM. The number of recaptured individuals was quite low to specify a consistent pattern. However, it was obvious that RBBs took-off at a later time because none remained at the platform. The findings strongly pointed out that the monitoring points have to be modified and expanded to 30, 50, 100, and 200 km.

Full moon releases

A total of 4,434 marked RBBs were recovered during FM releases over seven months (June-December 2009). This total represented 34.11% and 16.42% of the total bugs marked and released for FM periods and combined FM + NFM releases, respectively. Similar to NFM (Figure 3), the trend in number of recaptured bugs was highest in July (1,196 individuals) > August (760) > June (649) >September (638) > December (463) > October (399) > November (329) (Figures 8-9). It was clear that RBB migration during FM was several folds lower than that during NFM release except in August.

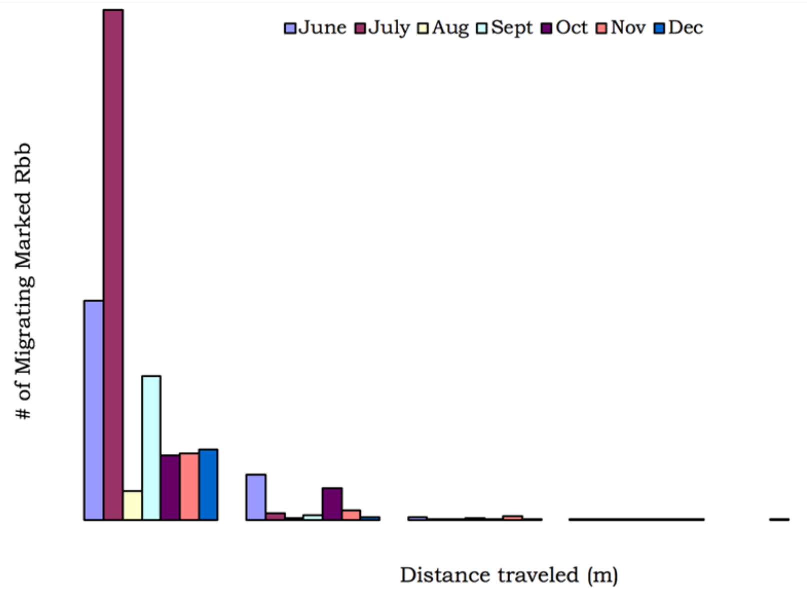


Figure 7. Distance traveled by migrating rice black bugs at the initial stage during non-full moon release periods in Mabca, Sangay, Camarines Sur.

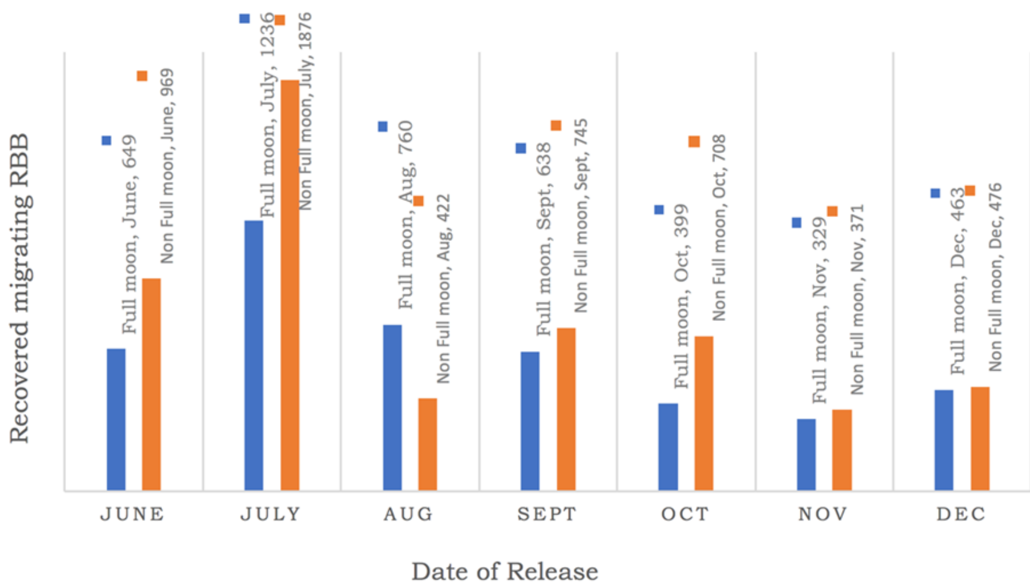


Figure 8. Monthly recapture of marked rice black bugs over a seven-month period, wet season, during full moon compared with non-full moon releases.

The distribution of recaptured RBB during FM releases was similar to that during NFM. It was also aggregated (X2=3,596.968, df=56; pooled value =2,418.732, df=6) and heterogeneity was also discordant (X2=1,178.236, df=50). Results of both releases confirmed the aggregative behavior of RBBs. Such behavior may be an adaptive feature to counter predation.

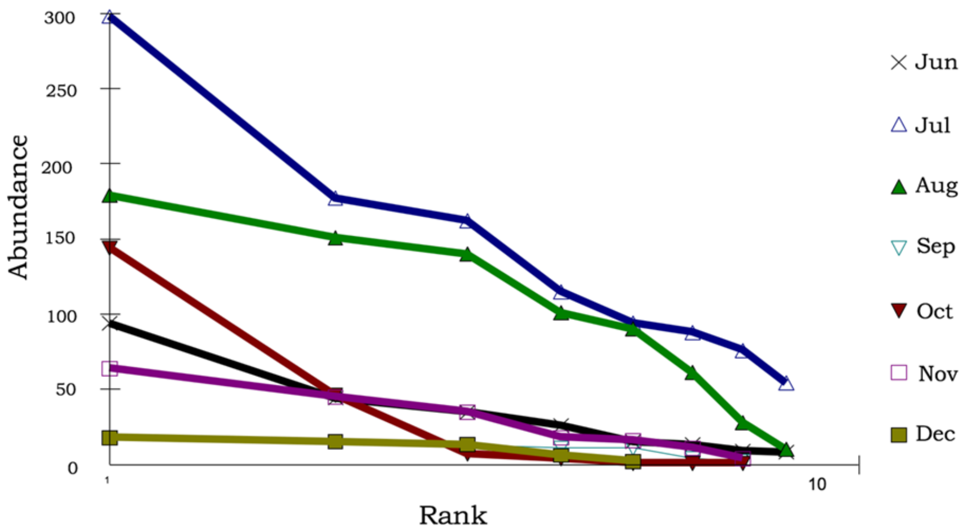


Figure 9. Rank abundance curve for the number of recaptured rice black bugs over a 7-month period during full moon release period.

The diversity (H1) and J1 values (Table 2) indicate that the trend in number of recaptured individuals was highest in July > August > September > June > November > December > October. Evenness (J'), on the other hand, had the following trend: July (0.934) > September (0.922) > August (0.902) > December (0.889) > November (0.867) > June (0.844) > October (0.438).

Based on Jaccard's single-link cluster analysis, the similarity of monthly catches of recaptured RBBs had three clusters (Figure 10). These were Cluster 1: June-July-August cluster with a similarity index (SI) value of 87.37%; September -October-November Cluster 2 with SI=87.22%; and Cluster 3 for December with a SI=71.37%. These findings may likely reveal that RBBs could be migrating according to the prevailing weather conditions.

The trend in FM releases was similar to that in NFM. A high percentage of the marked RBBs were confined to the 1-3 m radius of the monitoring points (Figure 11). However, the numbers were less than those in NFM releases. Nonetheless, the most common finding in both FM and NFM releases was that RBBs migrated long distances well beyond the 2.0 km radius. Some 26.21% (7,078 marked bugs) of FM and 29.63% (7,001) of NFM releases of RBBs were unaccounted for 36 hrs after release. The bugs may just be waiting for the appropriate wind direction to assist their flight.

The dispersion of marked RBBs based on the eight directional points and distance traveled indicates that their spread took many paths. In the June FM release, one bug reached the 20 m distance in the SE. In July, one bug reached 30 m away from release point at E and NE directions, while 12 bugs took four directions (W-NW-S-SE) in August. The trend in September was similar to that in August, while that in October was confined to N-W-NW paths. The farthest was recorded in November at 100 m along the NE direction. Dispersion in December was clumped evenly around the 1-3 m radius.

Table 2. Shannon's diversity values (H') and evenness (J') based on the number of monthly recaptured individuals of rice black bugs during the full moon release periods.

Indices	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H[1]	1.755	1.942	1.875	1.795	0.853	1.686	1.431
J[1]	0.844	0.934	0.902	0.922	0.438	0.867	0.889

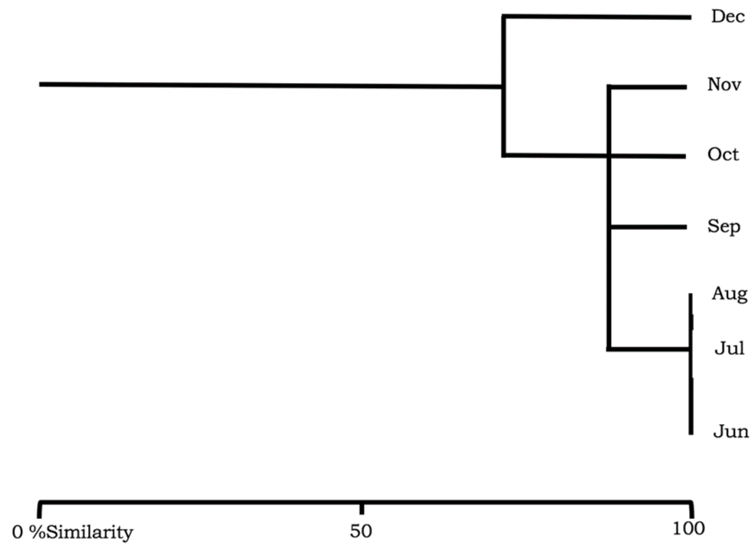


Figure 10. Jaccard's cluster analysis of the monthly migration of rice black bugs at the full moon periods.

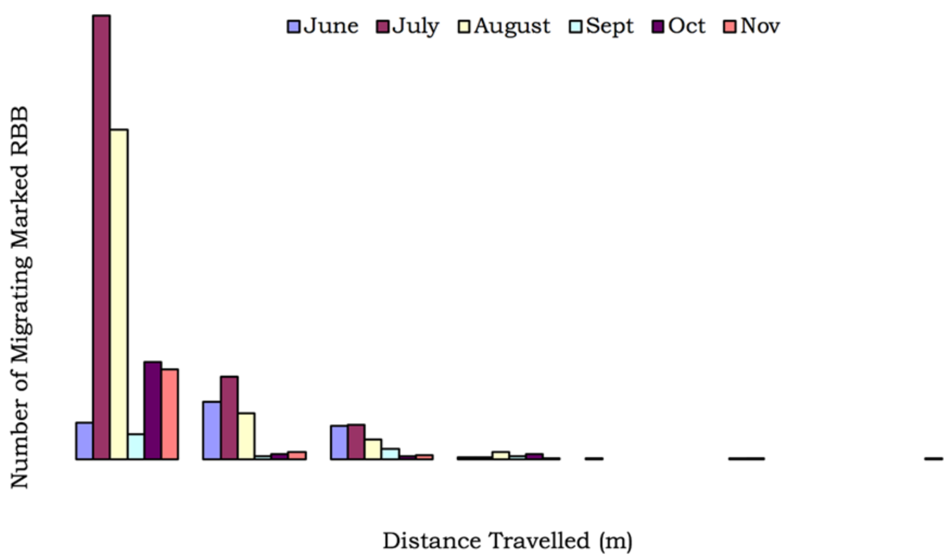


Figure 11. Distance (m) traveled by migrating rice black bugs in the early stages after the full moon releases.

Mark-recapture method and biodiversity

It may be coincidental, but the adoption of the mark-recapture method to assess migration and dispersal modes of RBBs provided deeper knowledge on the existence of nocturnal predators of RBBs at various developmental stages. Through this method, it was shown that the diversity of predators consisted of 28 invertebrates (i.e., arthropods) and a vertebrate. The following were found helping mitigate the population of RBBs in the field: four species of earwigs - *Chelisoches morio* (Fabricius), *Proreus simulans* (Stal), *Euborellia philippinensis* Srivastava, *Euborellia* sp.; 11 carabid beetles - *Ophionea nigrofasciata* Schmidt-Goebel, *O. interstitialis* Schmidt-Goebel, *Desera geniculata* (Klug), *Colliuris fuscipennis* (Chaudoir), *Eucolliuris* sp., *Anoplogenius microgonus* Bates, *Orthogonia* sp., *Chlaenius* sp., *Pheropsophus javanus* Dejean, *Pheropsophus* sp.n., and *Brachinus* sp.; a staphylinid - *Paederus fuscipes* Curtis; an anthicid - *Formicomus* sp.; three reduviid bugs - *Scipinia* nr. *rapax* Miller, *Euagoras plagiatus* Burmeister, and *Polytoxus* sp.; eight spider species in three families – Lycosidae: *Pardosa pseudoannulata* (Boesenberg & Strand), *P. birmanica* Thorell, *Pardosa* sp., *Arctosa tanakai* Barrion & Litsinger, *Trochosa* sp.; Oxyopidae: *Oxyopes javanus* Thorell, *O. lineatipes* Koch; and Thomisidae: *Runcinia albostriata* (Boes. & Str.). The most outstanding discovery was the nocturnal activity of the super predator, the toad *Rhinella marina* (L.), that recorded consumption of 808-1,214 adult RBBs per predation activity. All were nymphal-adult predators except the earwigs that demonstrated a strong preference for newly-laid RBB eggs.

General trends and recommendations

RBBs migrated in all directions adopting both short- and long distance flights almost equally during FM and NFM periods. The migration process was slow in the beginning, but bugs were recaptured rather quickly 24–36 hrs after release when wind and other environmental conditions were appropriate for flight. Recapture of migratory black bugs showed aggregate dispersal pattern. Marked black bugs were highly prone to predation by the toad, *R. marina*, with as many as >1200 bugs devoured in one setting.

Most rice black bugs were found on densely set hills of transplanted rice highly infected with bacterial leaf blight and other diseases in the field, and none at all on sparsely tillered hills of healthy direct-seeded rice. These findings were based on field observations made during field monitoring of RBB migration and collection of bugs for stock culture.

Based on the results of this study on RBB migration, previous knowledge on the bio-ecology of the bug and other important field observations, the following management protocols were recommended, namely: (1) shift in planting method from transplanting to direct seeding to prevent tiller compaction in a hill, that is most suited for RBB colonization; (2) stick to transplant method but plant fewer seedlings per hill (reduce number from 6-12 to 2-3/hill only); (3) use of bacterial leaf blight resistant varieties to push RBBs out of the rice field; (4) avoid use of insecticides to increase natural enemy population in the rice field; (5) apply fertilizer when there is minimal water in the field to allow the RBBs at the bottom and crevices to climb the plant and expose them to higher predation by natural enemies, followed by sufficient flooding to kill eggs already laid on the plant stems; (6) cut stubbles to ground level to remove the breeding grounds for RBBs and other insect pests after harvest; (7) flood and plow the field after cutting the stubbles to get rid of the bug population hiding in soil crevices; (8) practice duck-herding in the field whenever available and applicable to reduce the bug population in the field; (9) apply the fungus *Metarhizium anisopliae* (Metsch.) Sorok. to augment pathogen parasitism and increase mortality of RBB nymphs and adults; (10) practice light trapping for the bugs when there is a high bug population in the field, but bury the catch in a pit to become organic fertilizer; (11) adapt synchronous planting within a community to have rice-free period in the field to reduce incidence of RBBs; and (12) drain the water from the rice field when the rice crop is at the ripening stage.

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