PREDATION IMPACT OF CATTLE EGRET (*BUBULCUS IBIS*) ON MIGRATORY LOCUST (*LOCUSTA MIGRATORIA CAPITO*) AND RED LOCUST (*NOMADACRIS SEPTEMFASCIATA*) IN SOUTH AND SOUTHWEST REGIONS OF MADAGASCAR

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Abstract. Locust outbreaks in Madagascar cause economic damage, and biological control is an environment friendly option. This paper determined the predation values of *Bubulcus ibis* bird species as a measure that could contribute to an effective locust outbreak preventive control strategy. The study was conducted in the south and southwest regions of Madagascar that are heavily infested by red locust (*Nomadacris septemfasciata*) and the Migratory Locust (*Locusta migratoria capito*). Three types of experiments were done that included observed predation, potential predation and pecking frequency. The observed predation was 19 locusts per day in the outbreak period higher than recession period with a value of 3 locusts per day. The experimental predation was 54 locusts per day, and was higher than the observed predation in the outbreak period. The highest pecking frequencies were observed in Isoanala (mean = 20.34) followed by Bekily (mean = 8.34) and Tulear (mean = 5.75). The observations from Bekily and Tulear were significantly different (t (56) = 2.49, p = 0.000), because of vegetation type. In Tulear the vegetation was bushy and thick, which provided canopy for the locust unlike the savannah environment in Bekily. The use of birds in prevention of locust outbreak during recession was found to be interfered by other insects that were fed on by birds. Thus locusts can best be controlled by birds when their population increases in an outbreak. However, there is a need to assess the population of birds to determine if they were enough to predate on a locust outbreak.
Keywords: *pest management; gregarious and solitarious phase; pecking frequency; tropic agriculture; biological control*

Introduction

Locusts are a different kind of grasshopper that is specifically differentiated from other grasshoppers by their phenotypic plasticity, which causes the locusts to develop various phenotypic phases (Simpson and Sword, 2008). The various phases of locusts are responsible for determining the common population densities. There are two main locust densities that are characterized by low population known as the ‘solitarious’ phase and the swarm population called the ‘gregarious’ phase (Sánchez-Zapata et al., 2007). The solitarious form of locusts is found in isolation of one another, which is unlike the gregarious form that is attracted to each other to form swarms moving together. The gregarious locusts migrate in their large populations in search for food and the swarms contain immature and mature locusts. When locusts travel in such large numbers, they are known to cause damage to agriculture crop fields; making locusts the most destructive pest in tropical regions (Scanlan et al., 2001).

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There are locust species known to have a restricted geographical outbreak pattern, which has led to continuous locust outbreaks in specific areas (Magor et al., 2008). In Madagascar, the south and southwest regions have for decades had locust outbreaks that have devastated crop fields (Lecoq et al., 2011). The locust species dominant in this area are the red locust (*Nomadacris septemfasciata*) and the Migratory Locust (*Locusta migratoria capito*), both of which have geographically restricted outbreaks (Magor et al., 2008). Control of locust outbreaks in Madagascar has proven to be very difficult to control. Control methods of locust outbreaks in Madagascar have leaned towards use of insecticides, and use of organochlorine insecticide was preferred by farmers before it was banned. This kind of locust outbreak control is both expensive and leads to environmental pollution (Holt and Cooper, 2006; Gill and Garg, 2014).

The locust behavior in south and southwest regions of Madagascar follows the observed trends of locust plagues that breed successfully from solitarious to gregarious phase. To control locust plagues that have a geographical restriction, like in Madagascar, preventive control against pre-plague swarms is recommended (Steedman, 1999). There are different types of preventive control methods that have been used in different areas (Lecoq, 2001). Biological control of locust is deemed as a cheap and environmental friendly method, because it uses the pest’s natural enemies as a population control mechanism. Many bird species feed on locusts, but their ability to keep the locust population in check so as to avoid economic damage is not clearly known (Kirk et al., 1996). In this study, we considered the *Bubulcus ibis* (Cattle Egret) bird species in the area as a natural enemy for locusts. This was because the *Bubulcus ibis*, which is dominant in south and southwest of Madagascar, feed on locusts; hence act as a biological preventive control method. However, questions existed on the locust feeding capability of the *Bubulcus ibis* to be considered as an effective biological preventive option. This paper aimed at determining the predation values from the *Bubulcus ibis* as a contribution towards effective locust outbreak prevention. Furthermore, the study determined the predation values during both solitarious and gregarious phases.

Materials and methods

Study area

South and southwest regions of Madagascar are constituted by mosaic vegetation units that include Savannas, steppes, forest galleries, wastelands, and bushy areas. This makes these regions of Madagascar to be the hub for locust outbreaks. These regions, which are adjacent to each other, are bordered by the Onilahy River to the north, Mandrare River to the south, and Horombe plateau in the east. Based on the annual rainfall amounts, the area is divided into three ecological units that support growth and development of locust swarms. These three ecological units are initial multiplication area, multiplication transitional area, and final multiplication area. The initial multiplication area has sub-humid to semi-arid climate, and over 6 million hectares of herbaceous plant cover that receives annual rainfall of 750-800 mm. The multiplication transitional area has a semi-arid climate and over 2 million hectares of diverse graminaceous spectrum that is favorable for breeding of locusts; the area receives an annual rainfall amount of 400-500 mm. The final multiplication area in the southern coastal area has an arid climate, and covers an area of two million hectares of grass vegetation, which has an annual rainfall amount of 350-400 mm.

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Three sampling stations were selected on the three ecological units associated with locust swarm development. The three stations were Bekily,Tulear and Isoanala. Isoanala station located 23°50' south and 45°43' east, occupies an area of 3.75 km^2. The Isoanala station was an open environment that consisted of anthropic mosaic polyculture fields of various plant species such as *Acacia sp.*, *Indigofera sp.*, *Heteropogon contortus* (Poaceae), *Cynodon dactylon* (Poaceae) *Hyhaena Shatan* (Arecaceae) and *Eucalyptus sp*. This station had several water stations and was favorable area for locust to propagate.

The other stations of Tulear and Bekily are found between coordinates 23°21' to 24°05'14' south and 44°8'59' and 44°12'05' east, and covered a combined total of 1000 ha. These stations had locust exploration stations that have fertile soils that favor pasture growth and transhumance for farmers in surrounding areas. From the vegetation point of view, Tulear was green, however, the Bekily had a dry bush land dominated by *Heteropogon contortus* grass species. The Tulear station was classified as the multiplication area and Bekily was the gregarizing area.

Bird sampling

There are over 40 bird species in the study area of which 11 are known locust predators. Of these bird species, the *Bubulcus ibis* was selected because it was abundant in the study area and is a known biological pest control agent (Patankar et al., 2007). The *Bubulcus ibis* is resident to the study area and its population is spread over the entire area; this species is protected in Madagascar and has a rapid growth. The *Bubulcus ibis* is known to be a major predator of nymph and winged locusts.

Data collection and calculation

Studies of bird predation on locust were conducted from October 2012 to May 2013. Three types of experiments were done that included (i) experimental predation to estimate potential predation rate of birds on locusts; (ii) examination of captured bird stomach content; and (iii) determine the frequency of bird pecking per time unit. The results from these experiments were statistically measured for their significance by using t-test analysis.

Experimental predation (EP)

This experiment was performed at Antsakoaky station and involved capturing breeds that were placed in semi-natural cages. The cages were made of wire mesh installed directly on the ground, and were 2m x 1m x 1.5 in size. In each cage, individual birds of the two species were fed locusts of different developmental stages (nymph and winged); the locusts were fed in three different combinations of only nymph, only adult locusts, and a combination of hoppers and adults. The locusts fed to the bird were counted before being placed in the cages and the remainders were also counted to know the number of locusts not fed on. The birds in the cages were fed every morning and the remainders were removed in the evening of each day. This captive-feeding method was used to determine predation of an individual bird species on locusts of different development stages; calculated by using Equation 1.

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$$EP = \frac{\sum \text{Amount of locusts consumed per day}}{\text{Total days of experimentation}} \qquad \text{(Eq.1)}$$

Observed predation (OP)

Observed predation was done by examining stomach contents of hunted wild birds. It was based on determining the number of locust fed but also the development stage of the locust (whether nymph or adult). The stomach contents of birds were examined at different times of the day, and from different locations within the study area either in solitarious or gregarious periods. During stomach content examination, the presence of non-digestible components such as head, abdomen, femur, and wings were used to identify the captured locusts. This method also provided information on the period of day when the bird's predation of locust was highest. Equation (2) was used to calculate observed predation for individual bird per day.

$$OP = \frac{\sum \text{Total amount of locusts in the digestive tracts}}{\text{Total amount of birds captured}} \qquad \text{(Eq.2)}$$

Pecking frequency

To determine the frequency of bird pecking on locust per time unit, observations were made with the aid of Canon binoculars (model: 10x42 L-IS-WP). The birds were observed in the hunting grounds to record individual bird attempts, but also record locust capture attempts for birds while in flight. This observation was used to check consistency between number of pecks and observed stomach contents of the studied bird species. In good viewing conditions, this method represented the real predation of *Bubulcus ibis*. Each bird was observed for a time unit of five (5) minutes and the observations were done during different times of the day. Equation (3) was used to calculate the total number of bird pecks per day.

$$\frac{\text{Number of Pecks in 5 min x Average High feeding Period in a Day}}{\text{5 min (period of counting number of perks)}} \qquad \text{(Eq.3)}$$

Results

Observed predation

Observed predation (OP) of *Bubulcus ibis* was done by examining the bird's stomach contents to determine the number of locusts that were preferred and eaten. The OP was performed on the birds during two different periods of outbreak and recession of the two studied locust populations. In this paper, locusts refers to red locust (*Nomadacris septemfasciata*) and the Migratory Locust (*Locusta migratoria capito*); grasshoppers refers to locusts of other types and other forms of

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grasshoppers, while other insects refers to non-grasshopper/locusts. In each period, data were collected in the morning and afternoon in order to compare the time of day when the birds preferred to feed the most. In the locust outbreak period, the results showed that the 17 birds studied ate a total of 512 insects; 64 percent were the two studied locusts, 27 percent were other grasshopper species and 8 percent were other types of insects (*Table 1*). These results showed that during the locust outbreak period the birds ate a high proportion of these locusts than any other insect, because they were most in number and so easy to catch.

The calculated OP for the eaten insects in total was 30 insects per bird in a day, while in the morning and afternoon the OP's were 31 and 29 respectively (*Table 1*). The t-test statistic showed that there was no significant difference ($t(10) = 0.483$, $p = 0.639$) in the total number of insects eaten in the morning and afternoon, which meant that the birds had a constant eating pattern. However, the OP's for the birds on locusts was found to be significantly different ($t(14) = 2.71$, $p = 0.017$) between morning (OP = 23) and afternoon (OP = 14) feeding times (*Table 1*). This observation meant that the birds fed on the locusts mostly in the morning than they did in the afternoon. This locust eating pattern was because on the day of bird hunting there was rainfall in the afternoon, which prevented the bird's flight ability hence low OP. The OP's for grasshoppers was higher in the afternoon (12) than in the morning (6), although there was no significant difference. This was a response to the lower OP for locusts in the afternoon, which led to the birds to increase their feeding on other grasshoppers.

Table 1. *Observed predation of Bubulcus ibis during outbreak period*

Hunting time	Bubulcus killed	Insects in stomach				Percentage (%)of stomach content		
		Total insects	*Locusts*	*Grasshoppers*	*Others*	*Locusts*	*Grasshoppers*	*Others*
MORNING	OB1	31	29	2	0	93.98	6.45	0
	OB2	36	22	14	0	61.12	38.88	0
	OB3	24	23	0	1	95.83	0	4.17
	OB4	43	38	3	2	88.38	6.97	4.46
	OB5	35	33	0	2	94.28	0	5.72
	OB6	33	24	8	1	72.73	24.24	3.03
	OB7	31	28	3	0	90.33	9.67	0
	OB8	29	8	14	7	27.59	48.27	24.14
	OB9	18	10	3	5	55.55	16.67	27.78
	OB10	30	18	9	3	60	30	10
AFTERNOON	OB11	41	8	33	0	19.51	80.49	0
	OB12	13	6	3	4	46.16	23.07	30.77
	OB13	35	17	13	5	48.58	37.14	14.28
	OB14	37	19	16	2	51.36	43.24	5.4
	OB15	33	18	6	9	54.55	18.18	27.27

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	OB16	23	13	8	2	56.53	34.78	8.69
	OB17	20	15	5	0	75	15	0
Total		512	329	140	43	64	27	8

Calculation	**Parameter**	**Insects**	**Locusts**	**Grasshoppers**
Observed Predation (OP)	Morning	31	23	6
	Afternoon	29	14	12
	Day	30	19	8
t-test (*morning vs afternoon*)	t-stat	0.483	2.71	-1.51
	Degrees of freedom	10	14	8
	P values (two-tail)	0.639	0.017	0.171

In the locust recession period, the results showed that the 19 birds captured ate a total of 619 insects; 86 percent of the bird's stomach contents were grasshoppers, 9 percent were the studied locusts and 5 percent were other types of insects (*Table 2*). These results showed that during the recession period the birds ate a high proportion of other grasshopper species than the *Nomadacris septemfasciata* and *Locusta migratoria capito*. Similar to the outbreak period, the birds also did not eat significantly different (t (11) = 1.55, p = 0.148) between the morning and afternoon parts of the day (*Table 2*). A striking difference however existed between the OP's for the studied locusts and other grasshopper species, because there was a reduced population of the studied locusts it gave rise to other insects to dominate and increase their populations. This would be linked to the reduced competition that these other grasshopper species enjoyed in the absence of the studied locusts, which was not the case during the outbreak period. A comparison between OP's of the total insects between outbreak and recession periods showed no significant difference (t (23) = -0.425, p = 0.675) existed, supporting the observation that the birds fed the same amount in both periods.

Table 2. *Observed predation of Bubulcus ibis during recession period*

Hunting time	**Bird ID**	**Insects in Stomach**				**Percentage (%) of stomach content**		
		Total Insects	*Locusts*	*Grasshoppers*	*Others*	*Locusts*	*Grasshoppers*	*Others*
MORNING	RB1	58	11	47	0	18.97	81.03	0
	RB2	73	0	70	3	0	95.89	4.11
	RB3	36	7	29	0	19.45	80.55	0
	RB4	27	0	27	0	0	100	0
	RB5	73	0	71	2	0	97.26	2.74
	RB6	27	0	27	0	0	100	0
	RB7	11	0	9	2	3.7	85.18	11.12
AFTERNOON	RB8	14	3	11	0	21.43	78.57	0
	RB9	3	3	0	0	100	0	0
	RB10	4	3	1	0	75	25	0
	RB11	12	1	11	0	8.34	91.66	0

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	RB12	4	1	3	0	25	75	0
	RB13	36	7	18	11	19.43	50	30.5
	RB14	55	3	45	4	5.45	82.27	7.27
	RB15	8	8	0	0	100	0	0
	RB16	28	3	25	0	10.72	89.28	0
	RB17	49	2	46	1	4.8	93.88	2.04
	RB18	64	0	57	7	0	89.19	10.81
	RB19	37	1	36	0	1.56	98.44	0
		619	**53**	**534**	**30**	**9**	**86**	**5**
Calculation	**Parameter**		**Insects**		**Locusts**		**Grasshoppers**	
Observed Predation (OP)	Morning		44		3		40	
	Afternoon		26		3		21	
	Day		33		3		28	
t-test (*morning vs afternoon*)	t-stat		1.55		-0.15		1.77	
	Degrees of freedom		11		8		11	
	P values (two-tail)		0.148		0.883		0.104	

Experimental predation

The experimental predation (EP) was done to determine the feeding potential of the *Bubulcus ibis* on the locusts. This experiment was important as it took out any natural limiting factors that existed in the natural environment, in order to estimate how much the bird could predate on the locusts. During the experiment duration of 36 days, a total of 1282 larval and 1025 fledglings were fed to the caged birds. The results showed that 82 percent of the larval and 85 percent of the fledglings were fed on during this duration (*Table 3*). The EP for the nymph was calculated to be 39, while for the fledglings it was 38. The total EP was calculated to be even higher at 54 locusts, and most importantly was higher than the OP calculations. This was not surprising because the birds in the cages had no limiting environmental factors in the cage that could limit the bird's ability to hunt locusts. The environmental factors may include the bushy terrain, weather conditions such as precipitation limiting flight and competition just to mention a few. The EP results also showed that there was no preference for nymph or fledglings in the cage and that the bird's fed on the different combinations equally (*Table 3*).

Pecking frequency

The pecking frequency (PF) involved observing the birds in their natural environments, with the aid of binoculars, to determine the number of times a bird pecked on the studied locusts in a five minute interval. This observation was used to check consistency between number of pecks and observed stomach contents. Additionally, the observations were made in three different locations of Tulear, Isoanala and Berkily, which had different vegetation types (*Table 4*). The importance of observing birds at different locations was to assess the influence of vegetation type

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on locust predation by the *Bubulcus ibis*. The observations were also made in the outbreak and recession periods to further have quality comparisons. The highest PF were observed in Isoanala (mean = 20.34) followed by Bekily (mean = 8.34) and Tulear (mean = 5.75) in that order (*Figure 1; Table 4*). Isoanala observations were made during the fledgling's outbreak periods of *Locusta* and *Nomadacris* in the savannah fields of Madagascar. Apart from the increased population of the locusts that would make it easy for the *Bubulcus ibis* to feed, the savannah vegetation also plays an important role. The savannah vegetation is mostly grass with sparse tree canopies that do not provide an efficient ground cover to protect the locust or limit the birds hunting ability.

Table 3. *Potential predation of Bubulcus ibis*

Day	**Amount of locusts caged**		**Amount of locusts eaten**		**Percent eaten**	
	Larval	*Fledglings*	*Larval*	*Fledglings*	*Larval*	*Fledglings*
1	40		18		45	
2	40		23		58	
3	40		19		48	
4	40		26		65	
5	50		35		70	
6	50		38		76	
7	40	10	30	6	75	60
8	40	20	28	17	70	85
9	30	30	30	24	100	80
10		40		40		100
11		45		42		93
12	30	40	30	36	100	90
13	60		29		48	
14	50	10	30	8	60	80
15	50	20	50	10	100	50
16	50		38		76	
17	40		6		15	
18	48		46		96	
19	20	30	30	20	150	67
20	20	40	20	40	100	100
21	46	50	46	50	100	100
22		74		74		100
23		20		20		100
24		28		28		100
25	70	100	70	94	100	94
26	67	114	67	104	100	91
27		56		46		82
28		32				
29		51		51		100
30	60		60		100	
31	59		59		100	
32	30	36	18	36	60	100
33	12	49	11	49	92	100

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34	100	4	100	4	100	100
35	100	30	100	10	100	33
36		96		60		63
Total	**1282**	**1025**	**1057**	**869**	**82**	**85**
Expected predation	Larval		39			
	Fledglings		38			
	Total		54			
t-test (Larval vs Fledglings)	t-stat		0.189			
	Degrees of freedom		45			
	P values (two-tail)		0.851			

The observations from Bekily and Tulear were significantly different (t (56) = 2.49, p = 0.000), which meant the birds were feeding differently in the two locations. In Tulear the vegetation was bushy and thick, which provided canopy for the locust and made it difficult for the birds to effectively hunt. Contrary to the bushy environment in Tulear, the savannah environment in Bekily could not provide this vegetative cover and the bird's predation on locusts was higher even though it was during recession period. From these results, it can be concluded that using birds to predate in environments that provide good vegetative cover for locusts would not be effective to reduce the locust populations.

Table 4. *Summary of pecking frequency calculations based on sampling location*

Location	Average pecking frequency per 5 min	Average pecking frequency per day	Type of locust population	Vegetation Type
Tulear	5.75	249.55	Outbreak nymph of Locusta with fledglings	Bushy wasteland
Isoanala	20.34	882.47	Fledglings outbreak of Locusta and Nomadacris	Savannah with field of polyculture
Bekily	8.34	357.33	Locusta and Nomadacris in recession period and outbreak of secondary species	Tree savannah with grass meadow
Calculation	**Parameter**		**Values**	
t-test (Tulear vs Isoanala)	t-stat		-11.9	
	Degrees of freedom		34	
	P values (two-tail)		0.000	
t-test (Tulear vs Bekily)	t-stat		4.29	
	Degrees of freedom		56	
	P values (two-tail)		0.000	
t-test (Isoanala vs Bekily)	t-stat		9.67	
	Degrees of freedom		37	
	P values (two-tail)		0.000	

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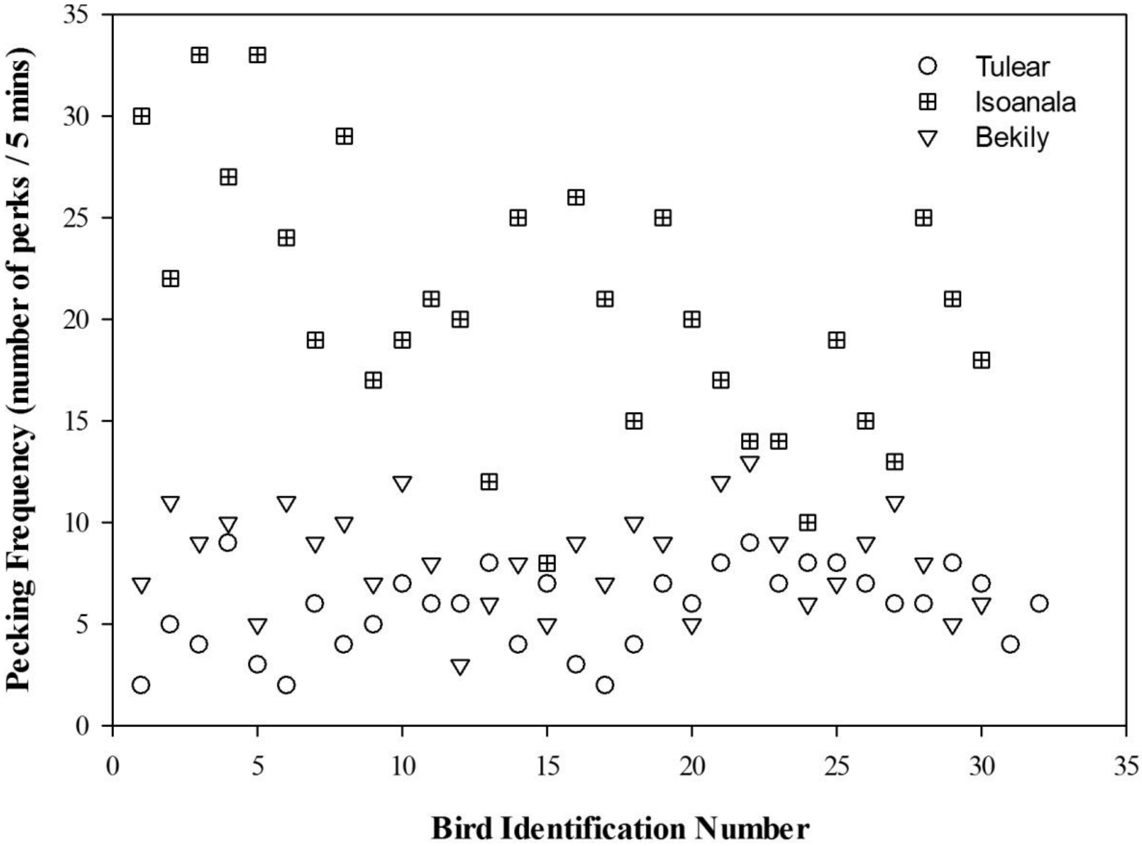

Figure 1. *Bubulcus ibis pecking frequency values in three locations of Tulear, Isoanala and Bekily.*

Discussion

Locust outbreaks in Madagascar, just like in many parts of the world need to be reduced to prevent the economic damage they cause through crop destruction. However, control of locust population in a cheap and environmental friendly manner is a challenge for agriculture pest management. Integrated pest management (IPM) is a known environmentally friendly method for pest management, which centers on the pests life cycle and their interaction with both living and non-living organisms in an ecosystem (Ahuja et al., 2015). The IPM approach is not a single method for control of pests, but rather a combination of environmentally friendly methods that together can be used effectively as pest management strategy. For instance studies on the use of entomopathogenic fungus known as *Metarhizium acridum* as a biological control has found it as environmentally good as it is highly selective with no side effects; however it was found to be slow acting and unreliable in its use to control locust outbreaks (Lomer and Langewald, 2001; Jin et al., 2008; Fang et al., 2014). In this study, the use of birds to predate on locusts has been evaluated as a locust mechanical control method that could be supplemented to already tried and effective strategies like the use of *M. acridum*. Three indicators (OP, EP and PF) were observed to determine the effectiveness of the *Bubulcus ibis* bird species in prevention of locust outbreaks. The results have shown that the birds do not feed on the locusts to their maximum ability in the natural conditions, because of limiting factors. In this study, rainfall and vegetative cover were the limiting factors that can also be expected in other similar locations. For

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birds to feed on the locusts, they target the insects that can easily be caught without spending much energy. However, in the presence of cover for the locusts the birds prefer to capture other types of insects. The type of vegetation plays a role in attracting the birds to feed on insects that feed on it (Jones and Sieving, 2006). Jones et al., (2005) in their study conducted on north-central Florida farmlands insectivorous bird activity was higher in polyculture crops than in monocultures. Thus it was normal to observe in our study that birds caught in savannah and partly dry forest had a high number of locusts in their stomachs. In some cases, such as where rainfall is a limiting factor, birds do not fly at all hence reducing their ability to predate on the locusts. The use of birds in prevention of locusts was found to be interfered by other insects available in the area. The presence of other insects meant that birds would not reduce a locust outbreak, because the birds predate on insects that can be easily caught. During the solitarious' phase the locusts population is lower than other insects and the numbers cannot be compared to an outbreak period. Most avian species have opportunistic traits in their feeding habits, switching food types to take advantage of readily available food sources. For instance, during an insect outbreak in a Polish forest, predation of passerine nests declined, as predators switched to feeding on caterpillars (Tomialojc and Wesolowski, 1990). Thus locust populations can be reduced by birds when their population increases in an outbreak or if there are no other insects for birds to feed on. Based on the perking frequency results, a large bird population would be needed to predate on millions of locusts that make a swarm. This study has shown that birds can effectively reduce locust population in an outbreak when they are easy to predate on. However, using the IPM concept of combining several methods, the use of environmentally friendly chemicals like *Metarhizium acridum* can be used because it makes hoppers more easily available to birds (Lomer and Langewald, 2001). Despite the discovery of this study, there is a need to assess the population of birds in locust infested areas to determine if the bird population is enough to predate on a locust outbreak and make an effective contribution to an integrated locust control approach.

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