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Ecological methods for adult populations of *Oryctes rhinoceros* (Coleoptera, Scarabaeidae)

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ABSTRACT. 1. For comparing assessment methods, *O.rhinoceros* (L.) populations were monitored in five 30–50 ha plots in southern Luzon, Philippines. No consistent correlations were found between number of beetles caught in traps, amount of palm damage and number of breeding sites. Apparently, plots were too small to account for fast dispersal of beetles.

2. Coconut cap traps baited with ethylchrysanthemumate attracted *O.rhinoceros* adults searching for breeding sites. Several factors were identified influencing catches but trapping was found to be unsuitable for accurately assessing pest populations.

3. A new method which gives estimates on the monthly number of *O.rhinoceros* attacks on coconut palms, was tested in the Maldives. Palms are climbed about once a year and the sequence of fronds, the number and the position of beetle cuts are recorded.

4. Reduction with age of the length of three teeth on the fore tibia of *O.rhinoceros* adults was studied in the Philippines. The data was insufficient to obtain a clear correlation between age and length of teeth.

5. The observations indicated that in the Philippines after leaving their site of pupation, *O.rhinoceros* adults spend about 5 weeks feeding on coconut palms. This is followed by a period of about 7 weeks in breeding sites and, on occasion, additional visits to palms. With these estimates it was possible to relate palm damage records with numbers of feeding adults.

Key words. *Oryctes rhinoceros,* coconut pest, ecological methods, attractant traps, population dynamics, age estimates, adult behaviour, Philippines, Maldives.

Introduction

In South-East Asia the rhinoceros beetle, *Oryctes rhinoceros* (L.), frequently causes serious damage to coconut and oil palms. Beetles bore into the palm crowns and feed on the young developing fronds. Breeding occurs mainly in decaying palm trunks, and if these are abundant, like after epidemics of palm diseases, typhoons, or during replanting, large-scale outbreaks often arise.

To improve cultural and microbial control methods, more detailed ecological knowledge of

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the pest is required. One of the more urgent tasks is to develop better techniques of quantitatively assessing adult populations of *O.rhinoceros*. As comparatively low beetle densities can cause high levels of palm damage, direct counts of beetles is usually impractical for monitoring and indirect methods like palm damage records and catches with attractant traps have been used. The main aim of our present investigations was to relate indirect assessment methods to actual numbers of beetles per area. In addition, we have studied ways of ageing beetles and of determining beetle behaviour in the field.

Coconut cap traps baited with ethylchrysanthemumate evolved from studies by Hoyt (1963), Barber *et al.* (1971), Maddison *et al.* (1973), Hinckley (1973) and Bedford (1973). Some observations (Bedford, 1973; Sabatini, 1979) have suggested that they attract *O.rhinoceros* adults searching for breeding sites but more detailed studies are needed to decide why and at what stage of their lives beetles visit these traps.

O.rhinoceros attacks produce characteristic cuts in palm fronds and the number of cut fronds has been frequently used as a measure for beetle abundance. However, it has been impossible to relate palm damage to number of beetle attacks per unit area per unit time and we are here proposing a new method of recording and analysing *O.rhinoceros* damage on palms which allows such correlation. The method uses information collected by Young (1975) on how beetles cause damage to palms.

O.rhinoceros adults cannot be aged satisfactorily except during the very early stage of their lives (Zelazny & Neville, 1972). We investigated the possibility of using the length of the three prominent teeth of the fore tibia, which gradually wear off, as an indication of age. A large-scale release/recapture trial was conducted to obtain data on the natural reduction of the tibia teeth.

Material and Methods

Coconut cap traps baited with ethylchrysanthemumate

Fifty traps, similar to those described by Bedford (1973), were operated between mid 1980 and mid or end of 1983 in each of five coconut plantations near the towns of Mauraro, Guinobatan, Ligao, Baao and Calabanga, in south-east Luzon, Philippines. The traps were placed along rows, about 50 m apart, and covered areas of 30–50 ha. They were baited once a week by applying ten drops of ethylchrysanthemumate directly to the lower surface of the caps around the central hole.

To relate trap catches with palm damage, 200 palms, approximately 15–30 years old, were marked near the traps in each location and *O.rhinoceros* cuts were counted from the ground twice a year. Palm density around the marked palms was determined and the damage was expressed as number of cuts per hectare on the upper half of the crowns.

The effect of *O.rhinoceros* breeding on the trap catches was studied in two ways. (1) In Baao and Calabanga, piles of 1 m long pieces of coconut trunk (about ten per pile) were established near the traps. The trunk sections totalled 600–700 in both locations. Twice a year the trunks were inspected to determine how many were occupied by *O.rhinoceros,* but were disturbed as little as possible. (2) Complete counts of *O.rhinoceros* stages in all breeding sites (see Zelazny & Alfiler, 1986) were done in three 9 ha plots in or near each trapping area except in Baao. In Calabanga two of the three plots were located just outside the trapping area and the third plot, which covered part of the trapping area and some of the trunk piles, was surveyed near the end of the trapping period.

The physiological state of beetles collected from breeding sites in a number of locations was compared with that of beetles trapped and removed from palms at Guinobatan. The endocuticle layers were counted (Zelazny & Neville, 1972) and females were dissected to determine the number of full-size eggs in their abdomen and whether they had previously mated.

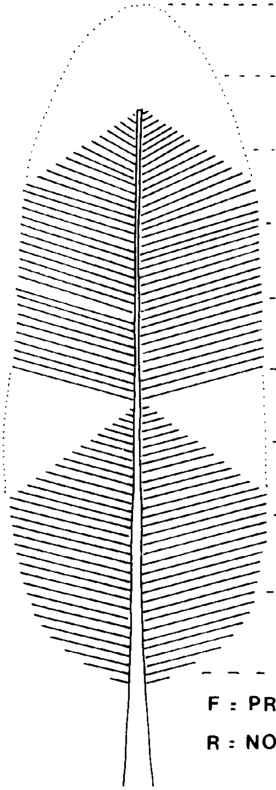
Trap catches at Guinobatan and the adjacent location near Ligao were compared with weather data collected at the Guinobatan site. Minimum temperature, rainfall, windspeed and relative humidity during the night were recorded.

Recording and analysing the number and positions of O.rhinoceros cuts on coconut fronds

Coconut palms produce a new frond every 3–4 weeks, and from the position of the fronds in the crown their age sequence can be determined. The youngest unfolded frond is here labelled 1, the next older frond 2, and so on. The oldest still folded frond (spear leaf) is labelled 0, the next younger frond (in the cabbage of the palm) −1, the next still younger frond −2, and so on.

Groups of forty palms were marked on two islands in the Maldives and were climbed in July 1984 and August 1985. From frond 2 onwards the surveyor determined for each *O.rhinoceros* cut the number of the damaged frond and, imagining the frond being divided into nine equal portions (Fig. 1), that portion in which the cut met the mid-rib. Frond portions, lost through knife cuts or through beetle damage (e.g. portion 1 in Fig. 1) were also recorded. Frond 3 was marked with paint and the number of new fronds produced since the previous survey was established. Recording was stopped when twenty fronds were examined or when the frond marked during the previous survey was reached.

By using the information given by Young (1975) the time a beetle caused a given cut was estimated. Although there is some variation between individual attacks and some differences correlated to the age of the palm, we have concluded from Young's data that on average an attacking beetle damages the fronds in the positions shown in Fig. 1 (first and second column),



PORTION	FROND NO. DURING TIME OF ATTACK	ESTIMATED MONTH OF ATTACK
1	−4	−(F+4)/R
2	−4	−(F+4)/R
3	−3	−(F+3)/R
4	−3	−(F+3)/R
5	−2	−(F+2)/R
6	−2	−(F+2)/R
7	−1	−(F+1)/R
8	−1	−(F+1)/R
9	0	−F/R

F : PRESENT FROND NUMBER

R : NO. OF FRONDS PRODUCED PER MONTH

FIG. 1. Example of *O.rhinoceros* damage on a coconut frond with division of the frond into nine portions used for recording and analysing the position of cuts. Two cuts are shown, the upper one in portion 2 has truncated the frond, the lower one in portion 6 has the shape of a double V. During a typical beetle attack the location of the damage on a given developing frond varies according to the position of the folded frond in the cabbage (middle column). This can be used to estimate the time of attack (last column). If the illustrated frond was the fifth unfolded frond ($F=+5$) and 1.1 fronds are produced per month ($R=1.1$) then the two cuts would be related to attacks 8 and 6 months before the time of observation. e.g. $-(5+4)/1.1=-8.2$.

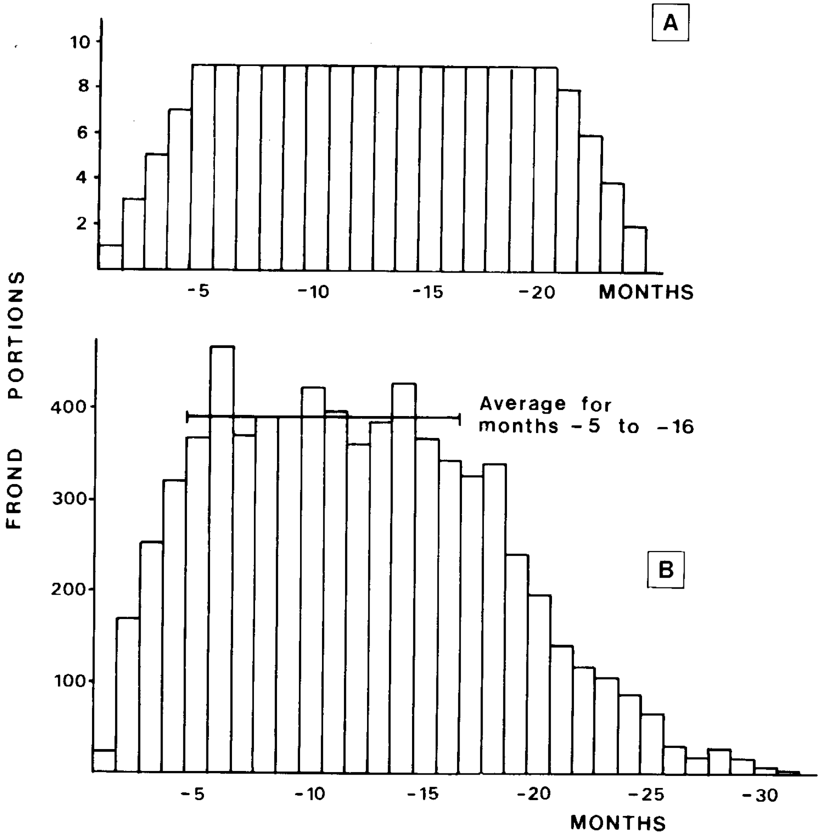


FIG.2. Assignment of coconut frond portions to the months before the observation using the formulae of Fig. 1. (A) For twenty fronds (F=1–20) of one palm (R=1); (B) for twenty fronds of forty palms with R varying from palm to palm as measured in the field on a group of forty palms.

the time of attack can then be estimated from the formulae given in the last column. The method, although allowing estimates on the time of attacks, does not result automatically in an estimate on the number of attacks during a given time period (e.g. 1 month). This complication is illustrated in Fig. 2. In Fig. 2A it is assumed that fronds 1–20 have been analysed as per formulae in Fig. 1 for a palm which has exactly one cut in each of the nine portions of every frond. The resulting assignment of portions to the months prior to the survey is shown for a palm producing exactly one frond per month. It is clear that even with uniformly distributed damage the number of frond portions assigned to different months is not always constant. Fig. 2B shows the accumulated assignments of frond portions from forty palms (twenty fronds each) with a natural range of frond production rates (average 1.1 per month). Further variations arise if fronds or frond parts are missing because of beetle damage or because people having removed them (e.g. for thatching).

In order to be able to compare the number of cuts assigned to different months it is necessary to use the maximum number of assigned frond portions as a common reference. This maximum is nine for one palm producing one frond per month (Fig. 2A), it is 396 (1.1×40×9) for forty palms and an average frond production of 1.1 per month (see average for months −5 to −16 in Fig. 2B). The procedure for estimating the number of beetle attacks per ha for given months was to: (a) assign the cuts to respective months using the formulae in Fig. 1; (b) repeat this for all frond portions except for portions cut off by knife or lost in beetle attacks; (c) estimate the number of cuts for a given month by multiplying result (a) by 396 and dividing by result (b); (d) divide the estimated cuts by 40 (number of palms surveyed) and by 4 (average number of cuts per attack) and multiply by the number of palms per hectare.

Obviously, the accuracy of the estimated cuts depends on the number of frond portions assigned to the particular month and no estimates were made if the assigned frond portions were less than half the maximum number. Since the above procedure involves large numbers of computations it is impractical without automatic data processing.

Release/recapture and ageing of beetles

On the evenings of 18 and 19 October 1984, 578 approximately 5-week-old mass-reared beetles (299 ♂ and 279 ♀) were marked on the pronotum with a small file and released in the centre of the Guinobatan trapping area. The beetles were recaptured within the 50 ha area by trapping, and by regularly searching young palms and decaying coconut trunks.

The right fore tibia teeth of freshly emerged beetles and of beetles recaptured in the above trial were measured from their tips to the basal ridge at its point of strongest curvature (Fig. 3) using a stereo microscope equipped with a measuring ocular. The combined lengths of the teeth ($A+B+C$) and the length of the tibia (D) were used to estimate the relative reduction of the teeth.

Results

Physiological state of trapped beetles

O.rhinoceros adults caught with attractant traps resembled closely beetles collected from

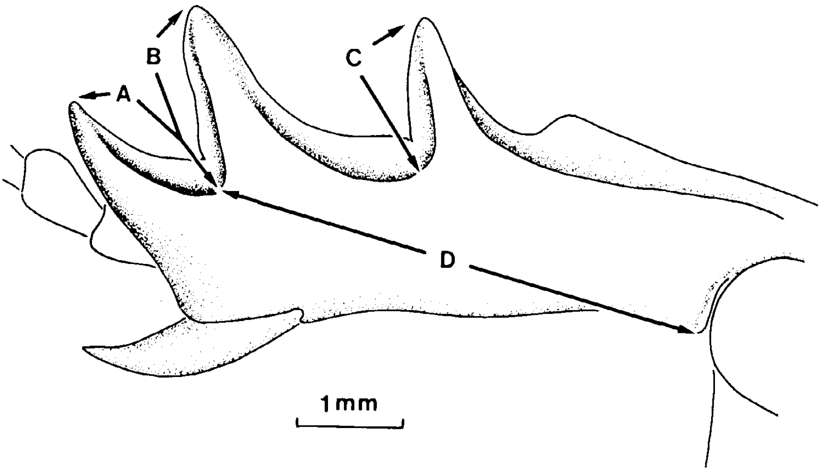


FIG. 3. Right fore tibia of *O.rhinoceros* with the distances measured to determine length of the tibia and its three prominent teeth.

TABLE 1. Physiological state of *O.rhinoceros* adults collected from coconut trunks, attractant traps, or palms.

	N	Source		
		Coconut trunks*	Traps	Palms
No. of males younger than 32 days (less than twenty endocuticle layers)	30	0	0	10
No. of females younger than 32 days (less then twenty endocuticle layers)	50	0	0	14
No. of females mated	100	96	96	33
No. of females with full size eggs in ovaries	100	88	97	34

*Beetles apparently freshly emerged from pupae were excluded.

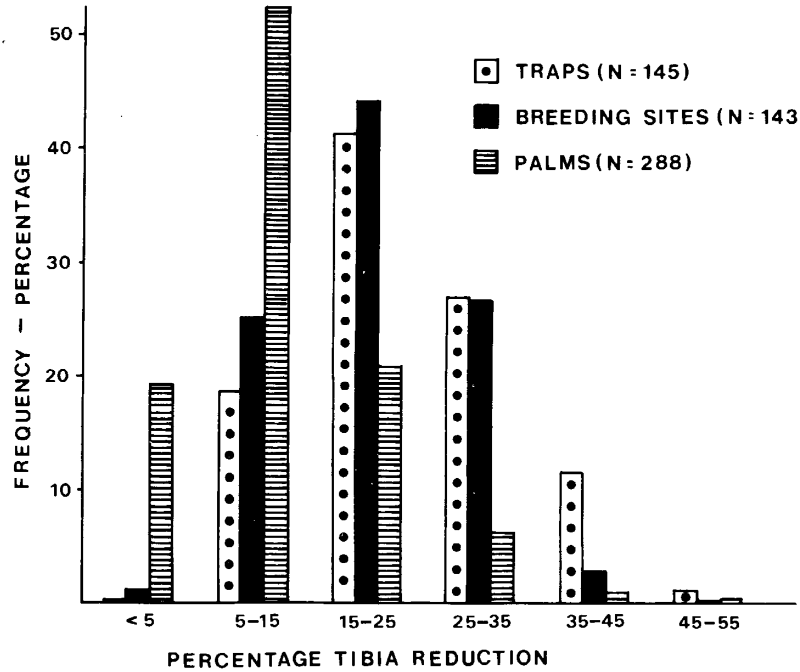


FIG. 4. Estimated reduction of the length of tibia teeth in groups of *O. rhinoceros* adults caught with traps or collected from breeding sites and palms.

decaying coconut trunks (breeding sites) but not those from the crowns of coconut palms (Table 1). None of the trapped beetles was estimated to be younger than 32 days and nearly all females were mated and contained full-size eggs in their ovaries. In addition, the reduction of their tibia teeth resembled more closely that of beetles found in breeding sites than that of beetles from palms (Fig. 4).

Correlation between trap catches, palm damage and breeding sites

In Baao and Calabanga, *O. rhinoceros* breeding in the log piles was followed by an increase in palm damage, but had apparently little influence on the trap catches (Fig. 5). Comparing breeding sites and palm damage in 9 ha plots with catches in adjacent traps at four locations did not indicate significant correlations between these variables (Table 2). However, Calabanga had an extremely high density of breeding sites, high palm damage, but the lowest trap catches. The low trap catches in Calabanga are also evident in the averages reported in the first part of Table 3. No consistent correlation between palm damage and trap catches was apparent for any location.

Environmental factors influencing trap catches

Between September 1980 and December 1983, the trap catches in Guinobatan and the adjacent area in Ligao showed no significant correlation with the average nightly windspeed, relative humidity, or minimum temperature. However, rainfall and a seasonal factor had a strong influence on the catches. Rainfall had two antagonistic effects, lower nightly rainfall resulted in higher trap catches (see also Bedford, 1975), but little total rainfall over longer periods reduced the catches, apparently because the caps dried out and became unattractive. The three variables nightly rainfall, dryness of the caps, and the seasonal factor were analysed by multiple regression (Table 4) and accounted for 35% of the variation of the trap catches. Periodic regressions fitted to the trapping data from all five locations showed that both the total catches as well as the proportion of males followed similar cycles (last two columns of Table 3).

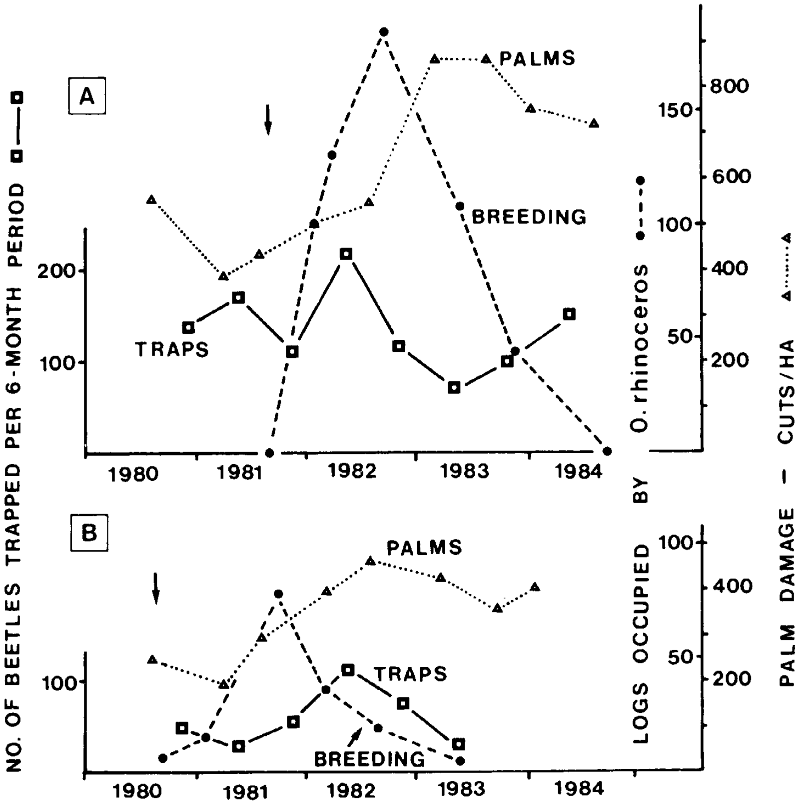


FIG. 5. Indicators of *O.rhinoceros* populations in two locations in Camarines Sur Province, Luzon, Philippines (A: Baao; B: Calabanga). The data relate to numbers of *O.rhinoceros* adults attacking palms or visiting traps, and to number of decaying palm trunks occupied by larvae or adults. Arrows indicate the establishment of log piles in which breeding was observed.

TABLE 2. *O.rhinoceros* breeding and palm damage in 9 ha plots compared to trap catches in the plots and/or in surrounding areas.

Location	Plot	Breeding sites		Palm damage (cut/ha)	Trap catches around survey date (5 months)
		No. per plot	No. of mature adults		
Mauraro	1	21	7	458	165
	2	47	7	154	103
	3	33	8	191	76
Guinobatan	1	87	9	172	148
	2	6	6	99	181
	3	10	0	297	69
Ligao	1	7	1	146	155
	2	18	3	211	59
	3	15	8	303	63
Calabanga	1	106	22	944	42
	2	153	53	651	38
	3	49	22	293	38

TABLE 3. *O.rhinoceros* trap catches in five locations (September 1980 to August 1983) compared with damage on palms surrounding the traps and correlated to seasons of the year.

Location	Average no. of beetles trapped/ month	Average palm damage, cuts/ha on upper fronds	Annual cycles of trap catches (acrophase and significance)	
			Total catches	Proportion of ♂
Guinobatan	22.6[a]	288[b]	March*	April
Mauraro	21.8[a]	212[bc]	June	May*
Ligao	22.0[a]	127[c]	April**	April**
Baao	22.8[a]	624[a]	May *	April
Calabanga	10.1[b]	349[b]	(January)	May

Averages followed by the same letter in the same column are not significantly different at the 1% level (Wilcoxon signed-ranks test). Asterisks indicate significant periodic regressions at the 1% (**) or 5% (*) level, the brackets in the last line indicate very low significance. Because of the nature of beetle attacks and growth of palms, palm damage records are compared with trap catches 2–10 months before the damage surveys to match populations of beetles visiting traps and attacking palms.

TABLE 4. Influence of rainfall and seasons on catches of *O.rhinoceros* with coconut cap traps in Guinobatan and Ligao (four variable multiple regression).

Variable	Mean	SD	Significance of independent variables	
			F	P
Dependent variable				
Y=weekly trap catches	9.88	6.45	–	–
Independent variables				
X_1=average nightly rainfall (mm)	4.61	8.29	29.0	<0.0001
X_2=dryness of caps (=number of weeks prior to trapping week which had an accumulated rainfall, day and night, of >20 mm)	2.67	3.50	28.3	<0.0001
X_{3-4}=seasonal cycle (t=week of the year)				
sin $6.92t$	−0.06	0.71	35.5	<0.0001
cos $6.92t$	0.04	0.70	6.7	0.0105

Regression equation: $Y=13.66-0.28X_1-0.83X_2+3.86 \sin 6.92t-1.54 \cos 6.92t$, or $Y=13.66-0.28X_1-0.83X_2-4.15 \cos (6.92t+68.3)$.

Analysis of palm damage

Fig. 6 gives the estimated number of *O.rhinoceros* attacks per hectare in two islands of the Maldives during 1983, 1984 and the beginning of 1985. Variations in the number of beetle attacks over the indicated period are apparent. On twenty-four islands of the Maldives, we compared this new method of beetle damage assessment with the old method of estimating the number of cuts per hectare. On each island, 160 palms were surveyed by the old method and forty by the new one. The 160 palms were observed from the ground and the number of fronds above horizontal and the number of *O.rhinoceros* cuts on these were counted. Every fifth palm was climbed by different observers and examined by the new method. Eight of the islands were surveyed twice in intervals of 6–13 months.

The old and new survey method gave surprisingly similar numbers of *O.rhinoceros* cuts. Palms observed from the ground (N=5120) had on average 0.696 cuts per frond and climbed

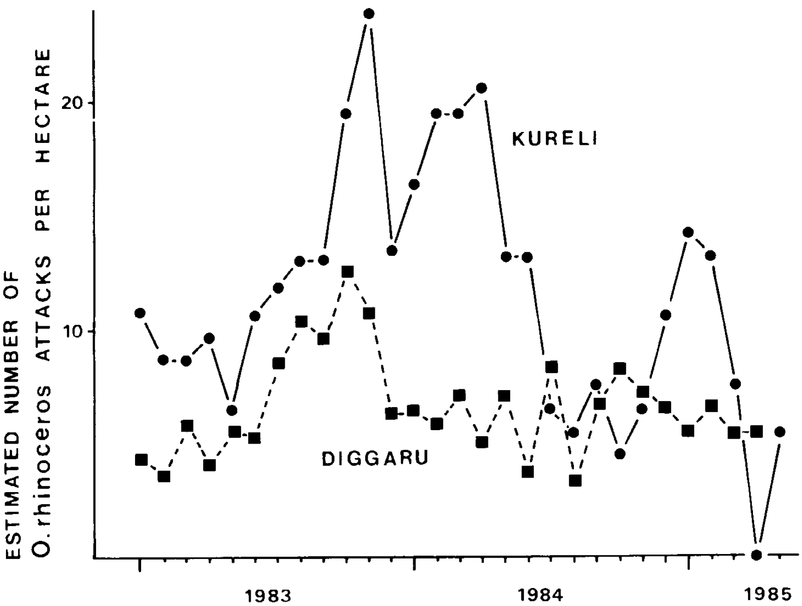


FIG. 6. Estimated number of *O.rhinoceros* attacks per hectare on two islands of the Maldives (Meemu Atoll) obtained after recording in July 1984 and August 1985 the number and positions of cuts on the fronds of forty palms.

palms (N=1280) on average 0.676 cuts per frond. Thus, both methods give reliable average counts that are apparently independent of individual palms and the observers, and regardless of whether palms were examined from the ground or scrutinized after climbing.

Reduction of tibia teeth and release/recapture

In freshly emerged *O.rhinoceros* adults, the relationship between tibia length D (see Fig. 3) and sum of the tibia teeth S ($=A+B+C$ in Fig. 3) fitted best the following two second order polynomials:

$S=-1.640+1.925\ D-0.087D^2$ (for males, N=87)

$S=-3.359+2.714D\ -0.156D^2$ (for females, N=59).

Reduction of the tibia teeth in wild or recaptured beetles was estimated by dividing the actual length of the teeth by the assumed 'original' length, derived from the above equations for a given sex and tibia size (see Fig. 4). However, the release/recapture trial gave few data on the correlation between age and tibia teeth reduction (Table 5). Beetles younger than 2 months (less than 4 weeks after the release) clearly showed less reduction in the teeth than older beetles, but there was little subsequent reduction with age.

Discussion

Estimating populations of *O.rhinoceros* adults poses two main problems. Firstly, the adult life appears to be divided into periods of feeding and breeding respectively and any single method would estimate either the adults attacking palms (mainly in the early part of the adult life) or the older breeding adults. No constant ratio of feeding to breeding adults can be assumed. Secondly, apparently beetles disperse quickly over large distances and tend to congregate in certain locations. For meaningful measurements it is therefore necessary to survey for both feeding and breeding adults, to collect large samples and to cover large areas. For example, the 30–50 ha study areas were apparently too small to obtain clear correlations between palm damage, trap catches, and the amount of *O.rhinoceros* breeding.

TABLE 5. Summary of release/recapture trial.

Weeks after release	No. of beetles recaptured (total number of beetles collected)		Survival in laboratory (%)*	Estimated reduction of tibia teeth in recaptured beetles (%)†
	Palms	Traps and breeding sites		
0	–	–	100	3.7
1	17 (28)	0 (4)	99	8.7
2	15 (27)	0 (7)	99	13.9
3	3 (13)	0 (5)	98	13.3
4	0 (18)	0 (6)	98	–
5	2 (23)	1 (12)	96	21.0
6	0 (12)	1 (4)	95	19.1
7	0 (11)	0 (16)	92	–
8	0 (22)	1 (13)	84	31.1
9	0 (6)	0 (16)	80	–
10	0 (7)	0 (20)	77	–
11	0 (7)	0 (14)	76	–
12	0 (9)	0 (13)	75	–
13	0 (2)	0 (13)	74	–
14	0 (7)	0 (15)	72	–
15	1 (7)	3 (9)	72	26.0
16	0 (2)	1 (16)	70	22.2
17	1 (8)	0 (9)	65	25.8
18	0 (3)	0 (10)	58	–
19	1 (4)	2 (13)	50	25.4
20	0 (3)	0 (11)	46	–
21	0 (3)	0 (6)	44	–
22	0 (8)	0 (10)	–	–

On 18 and 19 October 1984, 578 young beetles (299 ♂ and 279 ♀) were released in the centre of a 50 ha experimental plot. The average age of the released beetles was estimated to be 5 weeks. Beetles were recaptured in the experimental plot from young palms, attractant traps and decaying coconut trunks (breeding sites). The recaptures from traps and breeding sites were similar in number and time of occurrence and were combined.

*212 beetles of the same age were kept in the laboratory in moist sawdust and fed with bananas.
†Reduction of the tibia teeth was estimated from the teeth length, tibia length, and sex (see text). Note that percentage reduction was obtained from varying numbers of recaptured beetles.

For assessing the population of breeding adults, direct counts (Zelazny & Alfiler, 1986) are easiest to interpret and to use. Although the present observations confirm the hypothesis that coconut cap traps attract mainly breeding adults, the traps have several disadvantages for population estimates. For example, the data presented in Table 2 suggests that traps might have to compete with natural breeding sites, as would be expected from the conclusion that breeding adults are attracted.

Recording palm damage is the only practical way of assessing the population of feeding adults which could be in the order of one beetle per 100 palms under non-outbreak conditions. Counting the number of beetle cuts gives reliable data both if done from the ground or after climbing and such records can be related to the number of beetle attacks. Climbing is necessary if estimates on a monthly basis are required. The method proposed here of recording and analysing beetle damage on climbed palms is also more accurate since it can compensate for cuts which are no longer visible because they were on frond parts lost due to beetle attacks.

It is possible to derive from our results at an approximate correlation between palm damage and the number of feeding beetles per unit time and unit area. The release/recapture trial suggests that the first feeding lasts for about 5 weeks and that during this period the tibia teeth are reduced by less than 15% (Table 5). Of 288 beetles collected from palms in Guinobatan about 70% showed less than 15% reduction of the tibia teeth (Fig. 4), indicating that during the later part of their lives adults spend on average only an additional 2 weeks feeding on palms.

The duration of the different phases of adult life under conditions in the Philippines are summarized in Table 6. The duration of the breeding

TABLE 6. Approximate phases and durations of the adult life of *O.rhinoceros* under Philippine conditions. The last two phases occur simultaneously.

Phase	Description	Average duration (weeks)
Immature phase	Adults remain at site of pupation, endocuticle not complete, no or very little reduction of tibia teeth, females unmated and without full-size eggs	3.5
First feeding	In palms, endocuticle may be still incomplete, tibia teeth reduced by less than 15%, most females unmated and without full-size eggs	≈5
Breeding phase	In breeding sites, endocuticle complete, tibia teeth usually reduced by more than 15%, most females mated and with full-size eggs	4.5–5
Late life feeding	In palms, tibia teeth reduced by more than 15%	2
	Total. (approx.)	15

phase was estimated from earlier surveys of 477 ha of coconut plantation (Zelazny & Alfiler, 1986). A total of 351 immature (183 ♂ and 168 ♀) and 483 mature adults (237 ♂ and 246 ♀) were found in breeding sites. As the duration of the immature phase is 24 days (Zelazny, 1975) the ratio of the above figures suggests that mature adults spent on average 33 days in breeding sites. During the same study, the palm damage in the surveyed plantations was determined to be 334 cuts per hectare on the upper twelve fronds which is caused by approximately 1.5 feeding adults per hectare. (Since the total time adults spend in palms is estimated to be about 1.5 times longer than the time mature adults spend in breeding sites, 483 mature adults in breeding sites in 477 ha corresponds to 724 feeding adults, or 1.5 feeding adults per ha.) As twelve fronds are equivalent to 9 months (sixteen fronds are produced per year) one adult caused twenty-five cuts in 1 month (334/9×1.5) which is equivalent to about 6.2 attacks (four cuts per attack). Thus, dividing the number of attacks per month by 6.2 would give an estimate on the number of feeding adults, and one attack would last on average 5 days (30/6.2). This is in approximate agreement with the results by Hinckley (1973), who placed fifteen beetles in palms and observed that on average, they fed for 6 days.

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