Parameters for Coconut Rhinoceros Beetle Modeling

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Abstract

This document represents an attempt to extract parameters for modeling coconut rhinoceros beetle (CRB) population dynamics from the literature. A couple of review articles provided a good starting point: Bedford 1980 and Pallipparambil 2015. The only published journal article on modeling CRB population dynamics, Hochberg and Waage 1991, was also a useful reference.

1 Population structure

1.1 Table from Abidin et al. 2014

TABLE 1. NUMBER OF *O. rhinoceros* IN ZERO BURNING AND PARTIAL BURNING SITES

Stages of beetles	Zero burning		Partial burning		t value	p value	Sex ratio
	N	Mean ±SE	N	Mean ±SE			
Eggs	25	0.1736 ± 0.121	25	0.1736±0.211	t = 0.260 df = 143	p = 0.795	-
1st instar	48	0.3542±0.041	195	1.347±0.122	t = 2.139 df =143	p = 0.035*	-
2nd instar	364	2.500±0.025	341	2.299±0.032	t = 0.162 df = 143	p = 0.873	-
3rd instar	433	2.965±0.074	566	4.056±0.055	t = 0.373 df = 143	p = 0.710	-
Prepupae	12	0.0764±0.033	33	0.1667±0.014	t = 1.026 df = 143	p = 0.306	-
Pupae	30	0.1875±0.028	63	0.4375±0.025	t = 1.568 df = 143	p = 0.119	-
Adults	27	0.1875±0.017	41	0.2431±0.028	t = 0.917 df = 143	p = 0.361	(1:2) 21♂,47♀

Note: * Significant, $p < 0.05$.

Proportion of adults in zero burning is 2.9%, in partial burning it is 3.2%.

1.2 Table from Gressitt 1953

Table 16.—Estimates of Oryctes population in Ngiwal Village, 1951

Situation	Eggs	Larvae	Pupae	Adults	Total
Standing dead coconut palms	1,200	2,750	190	190	4,330
Coconut logs	700	1,800	70	70	2,640
Coconut stumps	1,400	3,800	100	100	5,400
Garbage and compost	1,300	3,000	100	100	4,500
Other palms, dead trees (including logs and stumps)	400	1,000	37	40	1,477
Live coconut palms (grown)	....	10	3	2,000	2,013
Live coconut palms (young)	....	....	......	500	500
In pupal cells (all habitats)	....	....	......	400	400
Totals	5,000	12,360	500	3,400	21,260

- Proportion of population in adult stage: 16.0%
- Proportion of adults in live coconut palms: 73.5%
- Proportion of population in live coconut palms: 11.8%

2 Coconut rhinoceros beetle (CRB) biology

Note: This section was written in preparation for an article on using harmonic radar to detect CRB breeding sites.

2.1 Life cycle and feeding behavior

Oryctes rhinoceros (Linnaeus 1758) (Coleoptera: Scarabaeidae: Dynastinae), commonly known as the coconut rhinoceros beetle (CRB) is a major pest of coconut and oil palm. CRB undergo complete metamorphosis with four distinct life stages: egg, larva, pupa and adult. Larvae feed exclusively on dead and decaying vegetation and cause no economic damage. Damage is done by adults of both sexes which bore into palm crownshafts to feed on sap to fuel their flight muscles. This boring activity typically damages several fronds developing within the crownshaft. When these fronds emerge and expand several weeks afterwards, the damage becomes visible as v-shaped cuts, a distinctive sign of CRB damage. Palms are killed only when the apical meristem (growing tip), located at the base of the crownshaft, is damaged by CRB boring activity. However, mortality caused by CRB is rare unless CRB population densities are high and palms are attacked simultaneously by multiple adults. Adults reside in palms only briefly, exiting bore holes within a few days to aggregate at breeding sites where they mate and lay eggs. Each CRB may feed up to 6 times during its adult lifetime (Vander Meer and Mclean 1975), boring a new hole each time.

From a survey of Ngiwal Village in the Palau Islands Gressitt 1953 estimated that 88% of the CRB population occurred in breeding site aggregations. The remaining 12% were adults which briefly left breeding sites to feed on sap in palm crowns. Breeding sites are found in a wide variety of decaying plant material including dead standing coconut palms, fallen coconut logs, rotting coconut stumps, and decaying wood of many tree species, piles of compost, sawdust, and manure. Severe CRB outbreaks often occur in response to massive amounts of decaying vegetation gemerated by typhoons, large scale land clearing and wars.

2.2 Invasion history

CRB is endemic to the tropical Asia region (including South East Asia). The beetle was inadvertently introduced into the Pacific in 1909 when infested rubber tree plants were transported to Samoa from Sri Lanka (previously known as Ceylon). The pest rapidly multiplied in Samoa and subsequently spread to several nearby Polynesian islands. Separate invasions further distributed CRB through Palau, parts of Papua New Guinea, and other Pacific nations through disruptions and uncontrolled movements during World War II . The invasive phase of the beetle was brought under control by the discovery and distribution of a viral biocontrol agent, Oryctes rhinoceros nudivirus (OrNV). OrNV causes persistent population suppression on many of the CRB infested Pacific Islands where it was introduced.

Detection of CRB on Guam in 2007 heralded a second wave of Pacific island invasions by this pest. Following a failed eradication attempt it was discovered that the Guam beetles are an OrNV resistant form which is being referred to as the CRB-G biotype . This problematic biotype has already spread to previously uninfested Pacific islands where it is damaging and killing coconut and oil palms.

2.3 Eradication programs

The recipe for eradicating coconut rhinoceros beetle from an island is simple:

- find and destroy all active and potential breeding sites
- prevent re-infestation by closing invasion pathways

However, eradication of CRB from an island has proven extremely difficult once this pest has become established. There have been many CRB eradication attempts and some are currently in progress. But there has been only one success. This was accomplished on the tiny (36 km^2) Niuatoputapu Island (also known as Keppel Island), which lies between Samoa and Tonga (Catley 1969). During a period spanning 1922 to 1930 all CRB breeding sites were located and destroyed.

We suggest that harmonic radar may be useful for efficient detection of CRB breeding sites, thus improving probability of successful eradication.

3 Parameters used in the Hochberg and Waage model

Table from Hochberg and Waage 1991:

TABLE 1. Biological interpretations, numerical values, sensitivities, and sources of the parameters used in the simulation model†

	Biological Interpretation	Value	Units	Sen‡	Ref¹§
a	Eggs laid per healthy breeder	5·60	10 days^{-1}	***	a,d
b	Eggs laid per infected breeder	0·64	10 days^{-1}	*	b
c_j	Development: juveniles	0·0595	10 days^{-1}	***	c
c_f	Development: feeders	0·0649	10 days^{-1}	**	d
c_b	Development: breeders	0·187	10 days^{-1}	**	d
m_j	DI mortality: juveniles	0·0474	10 days^{-1}	*	c
m_f	DI mortality: feeders	0·0152	10 days^{-1}	*	e
m_b	DI mortality: breeders	0·0152	10 days^{-1}	*	e
α_j	Virus mortality: juveniles	0·556	10 days^{-1}	*	f
α_f	Virus mortality: feeders	0·260	10 days^{-1}	**	b
α_b	Virus mortality: breeders	0·260	10 days^{-1}	*	b
β_{bj}	Trans: breeders ⇒ juveniles	0·0869	i^{-1} 10 days^{-1}	$\underline{*}$	g
β_{jj}	Trans: juveniles ⇒ juveniles	0·0019	i^{-1} 10 days^{-1}	$\underline{*}$	g
β_{ff}	Trans: feeders ⇒ feeders	0·1501	i^{-1} 10 days^{-1}	$\underline{***}$	g
β_{bf}	Trans: breeders ⇒ feeders	0·0330	i^{-1} 10 days^{-1}	$\underline{*}$	g
β_{fb}	Trans: feeders ⇒ breeders	0·0070	i^{-1} 10 days^{-1}	$\underline{*}$	g
β_{jb}	Trans: juveniles ⇒ breeders	0·0024	i^{-1} 10 days^{-1}	$\underline{*}$	g
ν	DD mortality: juveniles	0·005	j^{-1} 10 days^{-1}	$\underline{***}$	g

† Abbreviations: DI=density-independent; DD=density-dependent; Trans=transmission; i=infected donor; j=juvenile competitor.

‡ Sensitivity, or relative importance in the accuracy of parameter estimation according to sensitivity analysis: *** very important; ** important; * unimportant. Underline indicates that parameter estimates are based on least squares estimation (see text for explanation).

§ References: (a) Hurpin & Fresneau 1973; (b) Zelazny 1973a; (c) Zelazny & Alfiler 1986; (d) Zelazny & Lolong 1988; (e) Zelazny 1977; (f) Zelazny 1972; (g) see text for estimation procedure.

4 Life cycle

Table from Bedford 1980. Note that the column for CRB, *Oryctes rhinoceros*, was compiled using data from 4 sources:

Table 1 Duration in days of immature stages of some palm rhinoceros beetles

Stage	*Oryctes rhinoceros*	*Oryctes boas*	*Oryctes monoceros*	*Oryctes elegans*	*Scapanes australis*	*Strategus aloeus*
	(13, 20, 62, 80)	(75)	(82)	(81) mean	(13)	(84)
Egg	8–12	7	14	10	32	21
First instar larva	10–21	10	13	14	35	14
Second instar larva	12–21	14	12	21	45	21
Third instar larva	60–165	70	56	56	190	210
Prepupa	8–13	8	9	10	21	14
Pupa	17–28	15	17	14	45	42

5 Life table data

"A lab study by Indiravathi (2001) reported that approximately 63% of eggs and 87% of larvae successfully developed into adults." [Pallipparambil 2015]

"Small improvements in the average survival of larvae would explain the post-typhoon increases in Rhinoceros Beetle populations so often observed on Pacific islands. Assuming survival from oviposition to adult emergence is near 2 percent in a stable pop- ulation: a posttyphoon generation might increase 2.5 times with an average 5 percent survival in the numerous palm logs felled by the storm. A population decline would be expected only when preadult mortality exceeds 98 percent." [Hinckley 1973]

6 Life span and generation time

"The total life span in Palau may range from 150 to about 270 days, and I assume the average under normal conditions to be about 200 days. The pre-incubation period is about 12 to 20 days. The period from the of an egg to first egg of the next generation may be as little as 115 days. Thus, given favorable conditions, more than 3 generations my develop in one year." [Gressitt 1953]

"Unfavorable environmental conditions reduces larval size and prolongs development up to 420 d (Catley, 1969)." [Pallipparambil 2015]

7 Larval food conversion

"The minimum volumes per grub were 400 cc in a coconut log; 5000 cc in a kapok log; 7000 cc in a breadfruit log; 7000 cc in sawdust; and 9000 cc in grass compost." [Hinckley 1973]

8 Fecundity

"A female lays 70 to more than 100 eggs in its lifetime. Taking 90 as the average number of eggs laid by one female and assuming the sex ratio to be one female to one male, with an average life-cycle of 4 months to middle of egg-layng period for each female), the theoretical figure of 186,390 progeny per original female during one year (16,995,293,890 by the end of two years) is obtained." [Gressitt 1953]

"Both sexes mate several times and from studies of spermatophore residues in the bursa copulatrix of field collected females Hoyt (undated) estimated that there is a maximum of eight matings. However, field collected females have produced fertile eggs up to 130 days after being confined singly in cans of rotting sawdust which suggests that multiple matings are not essential. Egg production varies considerably depending on the longevity of the beetle and the suitability of the oviposition medium. Menon and Pandalai (1958) recorded up to 152 eggs per female although 90 - 100 would be more usual." [Catley 1969]

9 Sex ratio

"Of 282 specimens examined from Palau and Samoa, 142 were males and 140 were females. This suggests a ratio of 1.014 males to one female." [Gressitt 1953]

10 Flight distances

"The beetle is thought to prefer short flights, but is capable of long flights if local conditions are unfavorable (Catley, 1969). A lab study demonstrated that palm-fed tethered adult beetles had a flight potential of 2-3 h, covering the equivalent of 2-4 km (Hinckley, 1973). Reports of long distance flight by *O. rhinoceros* include adults flying toward light on a ship anchored 700 m from shore (Catley, 1969), marked adults recaptured at 900 m within 3d and approximately 1600 m within a month (Cumber, 1957). Kamarudin and Wahid (2004) used mark-release-recapture studies to determine the flight range of *O. rhinoceros* in oil palm replanting regions in Malaysia; their results suggested that the adults moved at the rate of 10-23 m/day and up to 1.3 km/week." [Pallipparambil 2015]

11 Number of adult feeding events (=attacks)

Vander Meer 1987 indicates that adult CRB feed 6 times between days 30 and 150 after eclosion from the pupa (see figure 4 in the article).

12 Probability of a palm dying as the result of CRB attacks

$$p(Mortality) = \begin{cases} 0, & \text{if } AR < LAR0 \\ \frac{AR - LAR0}{LAR1 - LAR0}, & \text{if } LAR0 <= AR <= LAR1 \\ 1, & \text{if } AR > LAR1 \end{cases}$$

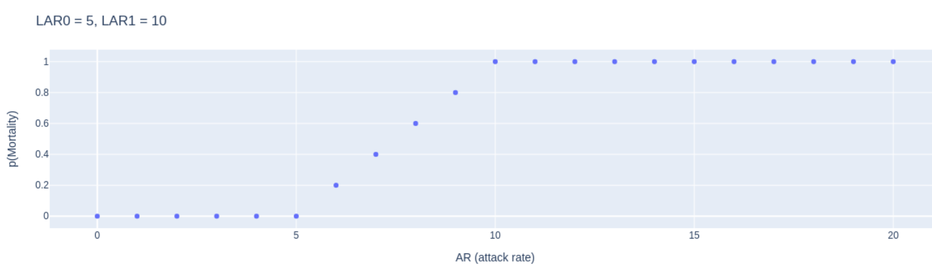
Where:

$p(Mortality)$ is the probablility of mortality of a palm tree immediately following a CRB attack

AR is the attack rate which is the number of simultaneous attacks (=bore holes) during a time period. In this model the time period is one CRB generation.

$LAR0$ is the highest attack rate which results in 0% mortality as a result of CRB.

$LAR1$ is the lowest attack rate which results 100% mortality as a result of CRB.



13 Detection level for economic damage

Hinckley 1973:

"The final goal should be a population reduction below the level at which economic damage[3] can be detected (Hinckley 1966).

[3] About 7.5 beetles/hectare (3/acre) on plantations in Western Samaoa."

14 Density of coconut palms on Guam

Estimated number of *Cocos nucifera* with DBH $>$ 5 inches growing on forested land on Guam (63,383 acres) is 1,162,494. [Donnegon et al. 2004]

This is 18.21 coconut palms per acre (= 45.00 per ha).

15 References

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