

DRAFT 1: Coconut Rhinoceros Beetle FIDL

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Figure 1: Male coconut rhinoceros beetle head and pronotum.

1 Coconut rhinoceros beetle (CRB) (Fig. 1), *Oryctes*
2 *rhinoceros* (L.) (Coleoptera: Scarabaeidae) is a ma-
3 jor pest of coconut palm and oil palm. It is na-
4 tive to southeast Asia, but it has invaded many
5 Pacific islands. American affiliated islands invaded
6 by CRB include American Samoa, the Republic of
7 Palau, Guam, Oahu (Hawaii), and Rota (Common-
8 wealth of the Northern Mariana Islands). With the
9 exception of American Samoa, these islands have re-
10 cently been invaded by a newly discovered variant of
11 CRB referred as the CRB-G biotype. This highly
12 invasive biotype is problematic because it is resis-
13 tant to *Oryctes rhinoceros* nudivirus OrNV, a clas-
14 sical biological control agent which previously con-
15 trolled CRB on Pacific Islands. Throughout this
16 leaflet, CRB-G refers to the virus-resistant biotype
17 and CRB-S refers to virus-susceptible biotypes which
18 can be readily controlled by OrNV.

1 Biology

1.1 Taxonomy

The coconut rhinoceros beetle (CRB), *Oryctes rhinoceros* L., is a member of the scarab beetle family, Scarabaeidae, and the subfamily Dynastinae. Taxonomic expertise is required to differentiate *O. rhinoceros* from several other similar *Oryctes* species, some of which also attack coconut and other palms.

1.2 Life cycle and reproduction

CRB has four life stages: eggs, grubs, pupae and adults with the grubs having three substages called instars (Fig. 2). The life span depends on environmental conditions, varying between 9 months and 18 months. Generation time varies between 5 months and 9 months. The CRB sex ratio is usually close to 50:50 and females lay about 65 eggs during their lifetime. Under optimal environmental conditions with an unlimited food supply, CRB populations have the potential to grow at a rate of 3,250% per generation.

1.3 Larval feeding behavior

Grubs feed only on decaying vegetation and do no harm. They feed in breeding sites which can be composed of a wide variety decaying vegetation. Preferred sites are standing dead coconut stems and fallen coconut logs and fronds. But breeding sites can be found in piles of a wide variety of organic material including green waste, dead trees of any species, saw dust, and manure. CRB breeding sites have even been found in commercially bagged soil purchased from hardware stores. Active breeding sites contain all CRB life stages.

It is interesting to note that CRB individuals are at their heaviest during the prepupal stage (third in-

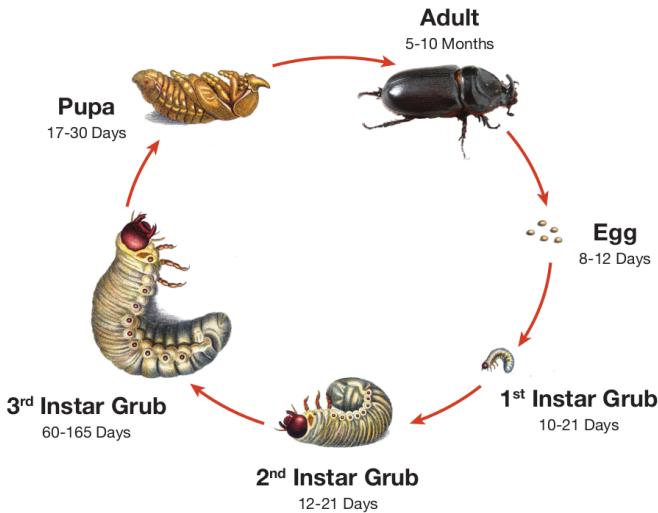


Figure 2: Coconut rhinoceros beetle life cycle.

age. If CRB caused a v-shaped cut, this can always be confirmed by removing outer petioles until a bore hole is found (Fig. 5 and 6).

Adults feed for only a few days in the crown before exiting the bore hole to fly off to a breeding site for mating and oviposition. Adults feed every few weeks during their adult lifespan. Thus a single adult can damage several trees.

The impact of v-shaped cuts reduces production of nuts and degrades the aesthetic appeal of ornamental palms. However, the damage is not necessarily permanent. Even severely damaged palms can be nursed back to full health if all further attacks from adults are prevented.

CRB can cause palm mortality if a bore hole damages the single meristem (growing tip) within the base of the crownshaft. Mature palm mortality caused by CRB is rare unless the adult population and the associated attack rate is very high.



Figure 3: Coconut palms severely attacked by coconut rhinoceros beetle.



Figure 4: V-shaped cuts caused by adult CRB.



Figure 5: CRB bore holes through petioles.

1.5 Population dynamics

With unlimited food and no control from natural enemies, CRB populations are capable of growing at a rate of about 3,250% per generation. Devastating, uncontrolled outbreaks of CRB are often triggered by a tropical cyclone, massive land clearing or military activity which generates large amounts of dead and decaying vegetation over a large area. Within a few months, this plentiful food supply generates massive numbers of adults which bore into palm crowns. The high rate of attack results in high palm mortality. These dead palms quickly begin to rot and become ideal CRB breeding sites, generating even higher numbers of adults which bore into and kill even more palms. In the absence of natural enemies or introduced biological control agents, this self-sustaining feedback cycle may result in the loss of most palm trees on an island.

An example of this positive feedback cycle occurred in Palau as a result of massive destruction of palms and other vegetation during the Second World War. Prior to the war, CRB was very rare in Palau but shortly afterwards about 50% of coconut palms were



Figure 6: CRB bore hole in stem made visible by removing petioles.

killed by CRB throughout the archipelago, and some islands lost all of their palms.

Uncontrolled outbreaks of CRB-G are currently happening on Guam and some of the Solomon Islands.

1.6 Geographic distribution

Islands in the Pacific and Indian Oceans were invaded by CRB during two waves of movement (Fig. 7). The first wave started in 1909 when CRB was accidentally transported to from Sri Lanka to Samoa with shipment of rubber tree seedlings and it ended during the 1970s. All of the CRB range expansion during this period was south of the equator except for the invasion of the Ryuku Islands (Japan) starting in 1921 and invasion of the Palau Islands prior to 1943.

The second wave of CRB invasions started in 2007 with discovery of CRB on Guam, followed by invasion of Oahu (Hawaii), Port Morseby (Papua New Guinea), Guadalcanal, Savo and Malaita (Solomon Islands), and Rota (Commonwealth of the Northern Mariana Islands). Beetles in the second wave of invasions are genetically different from those in the first wave and these are being referred to as the Guam biotype or CRB-G for short.

2 Control tactics

2.1 Eradication

In theory, eradication of CRB from a newly invaded area can be attained by blocking invasion pathways coupled with finding and destroying all breeding sites. In practice, eradication has proven to be very diffi-



Figure 7: Screenshot of an online interactive web map showing the geographic distribution of the coconut rhinoceros beetle. Green markers: native range; Orange markers: first detected during the 20th century; Red markers first detected during the 21st century; Open circle: population includes CRB-G biotype; Filled circle: population is exclusively CRB-G biotype.

153 cult after initial establishment of a CRB population,
154 despite early detection and rapid response.

155 Only one of many eradication attempts has suc-
156 ceeded. This was accomplished on the tiny (36 km^2)
157 Niuatopapu Island (also known as Keppel Island),
158 which lies between Samoa and Tonga. During a pe-
159 riod spanning 1922 to 1930 all CRB breeding sites
160 were located and destroyed.

161 2.2 Sanitation

162 Sanitation includes detection and destruction of ac-
163 tive and potential CRB breeding sites.

164 **Breeding site detection** Local searches for breed-
165 ing sites are usually initiated in response to visible
166 damage to palms or capture of adults in pheromone
167 traps. In Guam and Hawaii, dogs trained to sniff
168 out CRB grubs have been deployed to assist human
169 searchers. Recent research suggests that CRB adults
170 fitted with miniature radio transmitters or harmonic
171 radar tags may be a cost effective way of detecting
172 cryptic breeding sites. The essential idea is that the
173 radio transmitters and tags will accumulate at breed-
174 ing sites where adults aggregate. These tags can then
175 be detected by ground and/or aerial surveys using ra-
176 dio receivers or harmonic radar transceivers.

177 **Removal of standing dead palms** CRB adults are
178 attracted to standing dead palm trees that have be-
179 gun to rot from the crown. Females will lay their

eggs in the rotting palm trunk and the develop-
180 ing larvae will feed on the decaying fibers near the
181 top of the trunk, which starts to decompose in the
182 center forming a protective tube for larval devel-
183 opment. As the larvae increase in size and strength of
184 their mandibles, they can penetrate further down the
185 trunk leaving a column of frass and cut fibers for the
186 early instars. Dead standing palms should be felled,
187 cut into pieces and burnt or buried to remove poten-
188 tial breeding sites. In some situations, larvae may
189 develop in the crown of live palms. This only occurs
190 where there are large accumulations of organic mat-
191 ter in the frond bases. The organic matter should be
192 removed where possible.
193

Disposal of dead felled palms Mature palm trees
194 will fall after being weakened by fungal diseases
195 (*Ganoderma*), after strong winds during tropical cy-
196 clones or after the felling of senile palms prior to re-
197 planting. Dead palms on the ground should be cut up
198 into manageable lengths or chipped prior to disposal
199 by burning or deep burial.
200

Covering of palm stumps Felled palms leave a
201 stump which is suitable for development of larvae as
202 it rots. In management of palm plantations in Asia,
203 where a zero-burning policy is in operation, ground
204 cover is planted shortly after felling to cover the de-
205 bris and make it less attractive to the flying beetles.
206 The legumes *Mucuna* spp. and *Pueraria javanica* are
207 ground cover plants that are commonly used, as they
208 will add nitrogen to the soil and cover the decaying
209 trunks.
210

Management of organic matter and compost
211 Heaps of organic matter, particularly palm debris,
212 provide excellent food material for development of
213 CRB larvae. Any deep piles of organic material will
214 be attractive to the egg laying females. Heaps of
215 fronds or empty fruit bunches are particularly sus-
216 ceptible. Sawdust from sawmills that process palm
217 timber is also a favorable resource for beetle devel-
218 opment. General compost, farmyard manure and even
219 organic garbage can provide sites for development of
220 the larvae. The first step in reducing the threat of
221 beetles emerging from composts is management of
222 the organic matter. Palm debris should be spread
223 among the palms to break down rapidly and release
224

225 nutrients rather than being piled in heaps. Compost
226 or farmyard manure should be turned regularly, and
227 larvae removed, or pigs and chickens can assist by
228 eating exposed larvae. In urban environments, or-
229 ganic material is often gathered during environmen-
230 tal clean-up and composted, but this may provide a
231 centre for re-infestation of the locality. Compost can
232 be sterilized or fumigated to kill larvae; however, this
233 process is energy-demanding and expensive. Ster-
234 ile compost will also be susceptible to re-invasion.
235 Where feasible, compost heaps can be covered with
236 netting to trap emerging beetles.

237 Burning CRB breeding material is the most de-
238 pendable method for removing the food source for
239 CRB grubs. In Hawaii CRB sanitation programs,
240 breeding site material is being burned on-site using
241 air-curtain burners and some is being trucked to a
242 waste-to-energy electrical power generation plant.

243 2.3 Trapping

244 CRB trapping can be used for different purposes in-
245 cluding surveillance for early detection, monitoring
246 growth and spread of a population over time, and
247 for population suppression by mass trapping. In all
248 cases, the trap needs to be attractive enough to draw
249 in beetles from a distance strong and enough to con-
250 tain them once they are captured. Olfactory and
251 visual attractants can be used to increase trap catch.

252 **Artificial breeding sites** One of the first traps to be
253 developed was the Hoyt trap made from a metal can
254 set on top of a coconut trunk or wooden post (Fig. 8).
255 The can was capped with a length of coconut stem
256 with a hole in the center large enough for a beetle
257 to enter. The trap system was used extensively and
258 functioned because it mimicked a standing, decaying
259 coconut stem which is attractive to CRB adults.

260 An artificial breeding site trap can easily be con-
261 structed simply by laying coconut log sections on the
262 ground (Fig. 9). Trap catch can be enhanced by
263 covering the logs with netting (see section on netting
264 below) and providing a pheromone source.

265 **Pheromone traps** Design and utility of traps
266 changed with the discovery of ethyl chrysanthemate
267 as an attractant. This was rapidly superseded
268 by ethyl-4-methyloctanoate (E4-MO) commonly re-
269 ferred to as oryzcalure, the male-produced aggrega-

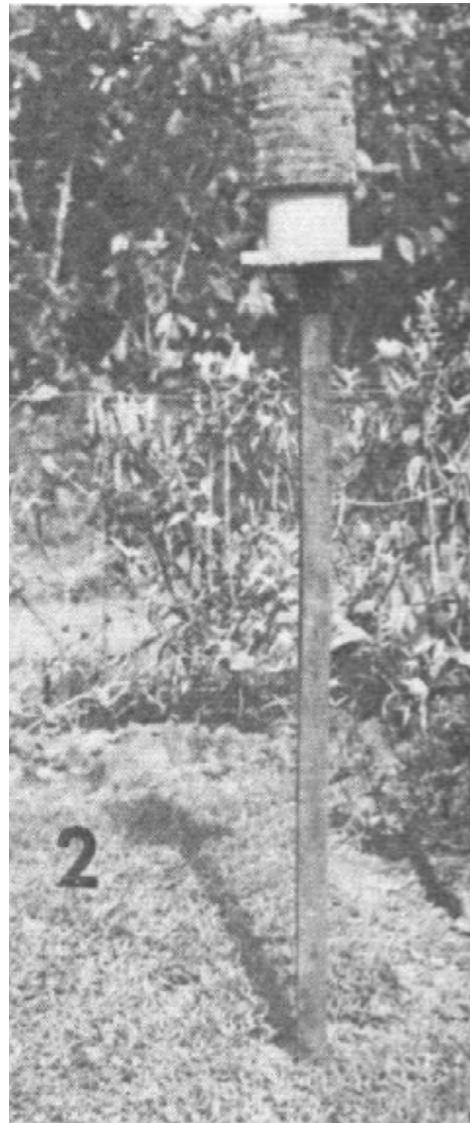


Figure 8: A Hoyt trap for capturing CRB adults.

270 tion pheromone of CRB, which could be synthesized. 270
271 E4-MO attracts both sexes, has been used for more 271
272 than 30 years and is produced commercially by sev- 272
273 eral companies. 273

274 Pheromone traps for surveillance need to be ro- 274
275 bust, inexpensive, attractive to beetles, difficult to 275
276 exit and simple to service. Simple bucket traps are 276
277 used extensively for monitoring throughout the Pa- 277
278 cific Islands and Southeast Asia (Fig. 10). Vaned 278
279 bucket traps (Fig. 11) and panel traps (Fig. 12) 279
280 have been used in surveillance trapping in Guam and 280
281 Hawaii where thousands of traps have been deployed 281
282 to monitor of the spread of CRB populations and 282
283 success of control activities. 283

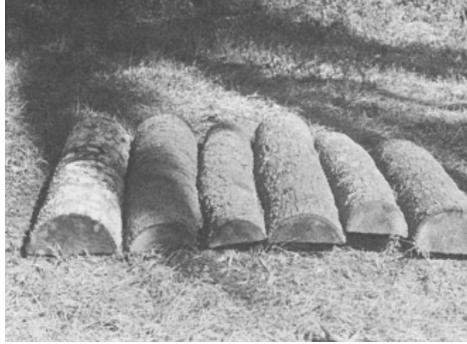


Figure 9: A log trap for capturing CRB adults.



Figure 10: A bucket trap for capturing CRB adults. An oryctalure dispenser is hung from the lid, inside the bucket. Beetles enter through holes in the top and sides of the bucket.

284 **Efficacy of pheromone traps for population sup-**
285 **pression** Trapping removes adults from the popula-
286 tion and may contribute to pest and damage reduc-
287 tion. Bucket traps baited with pheromone have been
288 reported to reduce CRB populations in Malaysia and
289 the related *O. monoceros* in West Africa.

290 However, efficacy of pheromone traps for popula-
291 tions of CRB-G is in question. Mass trapping was
292 performed on Guam shortly after detection of CRB
293 in the Tumon Bay hotel area in 2007. There was no
294 indication of population suppression and trapping did
295 not reduce damage to palms with the mass trapping
296 areas. During 2010, the trap catch rate in Tumon
297 Bay was only 0.006 beetles per trap day, but CRB



Figure 11: A vaned bucket trap for capturing CRB adults.
An oryctalure dispenser is visible at the center of the vanes.

298 damage was visible in 100% of coconut palms. In
299 contrast, a similar mass trapping program in Samoa
300 trapped 0.150 per trap-day, 25 times the Guam trap-
301 catch rate, but the proportion of damaged coconut
302 palms was only 30%. Note that the Guam population
303 is the CRB-G biotype and the Samoan population is
304 the CRB-S biotype.

305 Three possible explanations have been suggested
306 to account for these observations:

- 307 1. Traps baited with oryctalure are more attractive
308 to CRB-S than CRB-G.
- 309 2. CRB-G individuals do far more damage than
310 CRB-S individuals.
- 311 3. At very high population levels and trap densi-
312 ties there is so much pheromone in the air that
313 beetles cannot navigate to pheromone sources.

314 In mark-release-recapture experiments on Guam
315 only 64 of 567 (11%) of marked beetles were re-
316 captured in a grid of traps baited with oryctalure,
317 indicating that oryctalure is not highly attractive to
318 CRB-G biotype. Unfortunately, there are no com-
319 parative data for the CRB-S biotype.



Figure 12: A commercially manufactured panel trap for capturing CRB adults. An oryzcalure dispenser is hung in the rectangular hole at the center of the vanes.

Netting Tekken, a gill net used by Chamorro fishermen on Guam, has proven to be an effective trapping tool for coconut rhinoceros beetles. Beetles are captured when a strand of the netting falls into the gap behind a beetle's pronotum, in the same way that fish are caught when a strand falls into a gill slit (Fig. 13). In Guam, heaps of organic waste are covered with tekken which traps outgoing beetles emerging from the pile and incoming beetles attracted to the heaps for mating and oviposition (Fig. 14).

Cheap and simple pheromone traps can be made by attaching pieces of tekken to fences and placing an oryzcalure dispenser at the center of each piece (Fig. 15).

2.4 Chemical control

Chemical control of CRB is difficult because all life stages live in protected habitats: grubs and adults may be found inside dead logs or buried in or under heaps of decaying vegetation and adults may be found boring into palm crowns only briefly, for a few



Figure 13: A CRB adult captured by tekken fish netting.



Figure 14: Tekken fish netting used to cover a pile of greenwaste.

days during feeding bouts.

Federal and state pesticide regulations should be checked before planning any chemical control activities.

Foliar application Foliar insecticide application is aimed at preventing damage or mortality of palms caused by adults. The pyrethroid, cypermethrin has been used to successfully protect coconut palms and oil palms. A high enough volume should be applied so that the pesticide runs down the midrib and pools at the base of the petiole where it meets the crown-shaft. This is the location at which CRB adults initiate bore holes. Foliar sprays may be applied by hydraulic sprayers or by pesticide applicator drones.

Trunk injection Trunk injections of systemic insecticides have been applied to oil palms and coconut palms with variable success.

Treatment of breeding sites Cypermethrin applied as a drench controls all life stages in heaps of loose breeding site material, but may not kill adults and grubs living inside logs.

2.5 Biological control

Biological control is the use of natural enemies (predators, pathogens, parasites) to suppress pest



Figure 15: A Defence trap for trapping CRB adults. Constructed by attaching a piece of tekken fish netting to a fence and hanging an oryctalure dispenser near the center. The dispenser shown here has the oryctalure covered by an upturned cup to protect it from the sun and wind. Above the cup is a solar powered ultraviolet light emitting diode which increases trap catch by about 3X.

populations. In its native range, CRB is attacked by a community of co-evolved natural enemies, including pathogenic viruses and fungi, predatory carabid and elaterid beetles and parasitic *Scolia* wasps. The relative impact of each natural enemy species within this native community is poorly known, with additional control strategies often needed to complement biological control in coconut and oil palm plantations.

When CRB-S invaded the Pacific, it was the focus of a substantial biological control program. The aim was to find one or more natural enemies in the native range that could be introduced to the invaded range to suppress CRB-S populations. This process is known as classical biological control. Among many natural enemies introduced to the Pacific, very few predators or parasites established. Incidental predation by pigs and chickens on CRB larvae may assist with control of this pest and can be useful for control of larvae in household or community waste piles. Local species of generalist arthropod predators (centipedes, beetles, ants) may feed on CRB larvae; however, there is little evidence that this contributes significantly to CRB control.

Only one pathogen provided significant control of CRB-S: the *Oryctes rhinoceros* nudivirus (OrNV) discovered in Malaysia by Alois M. Huger in 1963. This virus infects CRB-S larvae and adults, causing death after 6–30 days. Infected adults are weakened prior to death so that they stop feeding, their mobility is reduced and females stop laying fertile eggs. Once established in countries invaded by CRB-S, the

virus significantly reduced CRB populations and the damage they caused.

Another approach to biological control for CRB was to create a biopesticide from a known pathogen. CRB adults and larvae can be infected by the fungus *Metarhizium majus* (formerly *M. anisopliae* var. *majus*). This fungus has been developed into a biopesticide that can be applied to CRB breeding sites in both the native and invaded range.

The recent invasion of CRB-G has changed CRB management wherever it is found. CRB-G is not susceptible to strains of OrNV introduced originally to control CRB-S in the Pacific. A new biological control effort is underway in order to identify strains of OrNV from CRB's native range that are effective against CRB-G. Until an effective OrNV strain is discovered, biopesticides containing *M. majus* are the only option for biological control of CRB-G.

In some jurisdictions, biological control agents are regulated as pesticides. For example, the U.S. Environmental Protection Agency regulates OrNV and *M. majus* as pesticides. Federal and state pesticide regulations should be checked before using biological control agents for CRB.

2.6 Damage surveys

A standardized method has been developed for quantifying CRB damage (for details see Jackson et. al 2020). This method uses a five-level scale illustrated in the following figures (Figs 16, 17, 18, 19, 20).

This method can be applied by direct visual observation or by scoring palms appearing in images. Research is underway to develop automated detection and mapping of CRB damage by applying computer vision techniques to images recorded during ground-based and aerial drone surveys.



Figure 16: **Damage index 0**; Zero damage; No CRB damage visible



Figure 19: **Damage index 3**; High damage; greater than 50% foliar loss



Figure 17: **Damage index 1**; Light damage; Notching or tip damage; less than less than 20% foliar loss



Figure 18: **Damage index 2**; Medium damage; Multiple fronds damaged; Notching and breakage; 20% to 50% foliar loss



Figure 20: **Damage index 4**; Dead or moribund; Meristem destroyed

431 2.7 Integrated pest management

432 Integrated pest management (IPM), is a broad-based
433 approach that integrates practices for economic control
434 of pests. The Food and Agriculture Organization
435 of the United Nations IPM as “The careful
436 consideration of all available pest control techniques
437 and subsequent integration of appropriate measures
438 that discourage the development of pest populations.
439 It combines biological, chemical, physical and crop
440 specific (cultural) management strategies and practices
441 to grow healthy crops and minimize the use of
442 pesticides, reducing or minimizing risks posed by pesticides
443 to human health and the environment for sustainable
444 pest management.”

445 IPM for management of CRB and includes combination
446 of the tactics described above.

447 For coconut palms planted for subsistence, ornamental
448 purposes, or in commercial plantations, IPM for CRB involves:

- 450 1. monitoring of palm damage to detect localized
451 CRB outbreaks and to check that control is successful
- 453 2. biological control with OrNV (in the invaded and
454 native range) and other co-evolved natural enemies (in the native range only)
- 456 3. sanitation to remove organic waste, dead palms
457 and other potential breeding sites

458 Sanitation is an essential component of IPM for
459 CRB that complements biological control. Localized
460 CRB outbreaks will occur when breeding sites are
461 left uncontrolled, especially after cyclones and tropical
462 storms, when palms are often toppled by high winds and large amounts of green waste is created.
463 Historically, outbreaks of CRB often follow cyclone damage or large scale land clearing. Larvae will develop in the decaying fronds, the trunk and even the roots of the felled palms and also in many other forms of decaying vegetation.

469 Some additional options may be incorporated into
470 IPM programmes for coconut, particularly for commercial plantations or ornamental palms. These
471 more costly options include pheromone traps to monitor adult beetle activity and complement it with visual surveys of palm damage. Occasionally, trap catches may be high enough to contribute to population suppression in coconut plantations, but this

477 strategy is more relevant to oil palm (discussed below). If a recent invasion of CRB is targeted for eradication, insecticides may be necessary for success.

478 For higher value crops, particularly oil palm, the same components are needed as for coconut: monitoring, biological control; and sanitation. More costly
479 IPM components are recommended for oil palm because the crop’s financial value makes greater investment in control worthwhile. Thus, IPM for CRB in oil palm involves:

- 480 1. monitoring of beetle activity with pheromone traps and palm damage particularly for young palms
- 482 2. biological control with OrNV (invaded and native range) and other natural enemies (native range) plus application of *M. majus* as a biopesticide to breeding sites that cannot be removed
- 484 3. sanitation to remove organic waste, particularly during plantation renewal when large amounts of waste is generated
- 486 4. insecticide treatments for young palms that are most sensitive to CRB damage.

490 Note that pollinators of oil palm are vulnerable to insecticides, so applications should be scheduled carefully to avoid flowering. When oil palm plantations are renewed, complete clean-up of the organic waste is challenging. In CRB’s native range, an additional strategy is to break up and spread the waste as a thin layer, then plant a fast-growing cover crop, often a legume, over the waste matter.

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