



United States
Department of
Agriculture

Animal and
Plant Health
Inspection
Service

Plant Protection
and Quarantine

New Pest Response Guidelines

Oryctes rhinoceros (L.) Coleoptera:
Scarabaeidae
Coconut Rhinoceros Beetle



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First Edition Issued 2015

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Cover Image

Coconut palm frond damaged by *O. rhinoceros* (photo courtesy of Arnold Hara, University of Hawaii)

Male adult of *O. rhinoceros* (photo courtesy of Pest and Diseases Image Library, Bugwood.org)

Coconut palms killed by *O. rhinoceros* in Fiji (image by Geoffrey Bedford printed with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

Introduction

The coconut rhinoceros beetle, *Oryctes rhinoceros* L., is a major pest of palms where endemic or introduced. Although abiotic and biotic factors may impact population dynamics, the pest distribution appears associated with its primary hosts—coconut and oil palms (see *Adult Hosts* and *Natural Dispersal* on pages 4-8 and 4-11, respectively). Damage is caused by adults feeding on the palm crown and terminal, with larvae primarily feeding on decaying palm residue. In the United States, this insect may affect tourism, property values, floral and faunal diversity and some threatened and endangered species (see *Damage* on page 5-1). The coconut rhinoceros beetle was recently reported in Guam and Hawaii and is therefore of concern to the southeastern United States where its hosts are abundant (see *Geographic Distribution* on page 4-13).

For information regarding the use of this document, refer to *Appendix A: How to Use the Guidelines*.

Taxonomy

Linnaeus originally described the species as *Scarabaeus rhinoceros* in 1758; in 1798, Illiger proposed the genus *Oryctes* (Brands, 1989-2005). The taxonomic classification of the coconut rhinoceros beetle is presented in [Table 2-1](#).

Table 2-1 Classification of the coconut rhinoceros beetle (Arnett *et al.*, 2002; Brands, 1989-2005; Schoolmeesters, 2014b; Triplehorn *et al.*, 2005)

Rank	Taxon
Phylum	Arthropoda
Class	Insecta
Order	Coleoptera
Suborder	Polyphaga
Superfamily	Scarabaeoidea
Family	Scarabaeidae
Subfamily	Dynastinae
Tribe	Oryctini
Genus	<i>Oryctes</i>
Scientific name (accepted)	<i>Oryctes rhinoceros</i> (L.)

In the Catalogue of Life (Schoolmeesters, 2014a), Scarabaeidae and Dynastidae are considered 2 separate families. However, Arnett *et al.* (2002) and Triplehorn *et al.* (2005) included the dynastids in the subfamily Dynastinae and in the family Scarabaeidae. Systema Naturae provides similar taxonomic classification (Brands, 1989-2005), which is utilized throughout this document.

Synonyms

- ◆ *Oryctes stentor* Castelnau
- ◆ *Scarabaeus rhinoceros* L.

Common Names

Coconut rhinoceros beetle is the preferred common name of *O. rhinoceros*. Table 2-2 provides a list of names common throughout the world.

Table 2-2 Common names for *O. rhinoceros* (Gressitt, 1953; Mohan et al., 2005; Schoolmeesters, 2014b)

Language	Common names
English	coconut rhinoceros beetle palm rhinoceros beetle rhinoceros palm beetle Asiatic rhinoceros beetle Indian rhinoceros beetle coconut palm rhinoceros beetle coconut palm beetle coconut black beetle black beetle coconut beetle date palm beetle dung beetle
Palauan	arm-ar-alius
Japanese	yashino kabutomushi Taiwan-kabutomush sai-kabutomushi
Samoan	manu-i-niu avi-i-vii
Tagalog	uang
Visayan	bakukang
Malay	kumbang badak kumbang kelapa
Dutch	klappertor
German	Indischer nashornkäfer
French	<i>Oryctes</i> du cocotier rhinocéros du cocotier
Spanish	escarabajo rinoceronte Asiático

Identification

Species Description/Morphology

The developmental stages of the *O. rhinoceros* beetle—egg, larva, pupa and adult—are presented in [Figure 3-1](#) with all morphometric measurements listed in [Table 3-1](#).



Figure 3-1 Developmental stages of *O. rhinoceros*. Top left to right: eggs, first, second and third instars; bottom left to right: pre-pupa, pupa (images by Geoffrey Bedford printed with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

Egg

A freshly laid egg is a cylinder that gradually absorbs moisture to become a rounded oval. As the hatch date approaches, the color can change from clear white to yellowish brown. The chorion is tough with minute granulations on its surface (Gressitt, 1953). [Figure 3-2](#) presents *O. rhinoceros* eggs and a first instar.

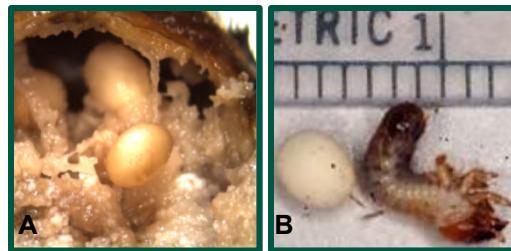


Figure 3-2 (A) Immature eggs inside a dissected female; (B) oviposited egg and first instar (photos courtesy of Aubrey Moore, University of Guam, and Arnold Hara, University of Hawaii)

Larva

The *O. rhinoceros* larva often curls into a crescent shape with the head touching the posterior end of the abdomen (Gressitt, 1953; Monty, 1978). A complete description of third instar larval morphology is available in the literature (Bedford, 1974).

Garlovsky *et al.* (1971) and Gressitt (1953) provided an overview of the larval morphology. The head capsule is dark reddish brown and sclerotized with strong mouthparts including the mandibles and maxillae (Figure 3-3). The mouthparts project outward from the head in a rounded triangular fashion. The antennae are 4-segmented and located on the dorsum at the base of the mandibles. The head lacks ocelli. Although the thorax of the larva has 3 segments each with a pair of legs, the margins are not typically distinct with only the first thoracic segment possessing a pair of spiracles. The larva has 10 abdominal segments, only the first 8 of which contain spiracles. The exoskeleton is transparent and off-white. The posterior end of an actively feeding larva is darker, possibly indicating the presence of a large, bacteria-filled “fermentation chamber” in the modified hindgut (Figure 3-3) (Crowson, 1981; Zhang and Jackson, 2008).



Figure 3-3 Third instar—sclerotized mouthparts and a dark abdomen (photo courtesy of Arnold Hara, University of Hawaii)

Instars

There are 3 instars, which can be differentiated by the size of their head capsules (Table 3-1, Figure 3-4). Due to weight loss prior to molting, the

larval lengths (8–100 mm) overlap significantly rendering weight inappropriate for identification.

Table 3-1 Body measurements of *O. rhinoceros* at different developmental stages (Gressitt, 1953)

Developmental stage	Character	Measurements (mm)
egg	fresh-elongate (L × W)	3.5 × 2.3
	mature-round	4 × 3.7
first instar	head capsule width ¹	2.5–3.1
	body length	7.6–25
	body width	2.5–7
second instar	head capsule width ¹	5–6
	body length	22–65
	body width	6–12
third instar	head capsule width ¹	9.5–11.2
	body length	60–105
	body width	10–20
pupa	body length	39.4–51.5
	body width	19.0–23.6
adult	male length	30–57
	female length	29–51

¹ Diagnostic feature used to distinguish the 3 instars

Immediately after hatching, the head capsule of the first instar appears whitish, becoming reddish brown during the first 24 hours of inactivity. The width of the head can exceed that of the body. The epicranial suture is visible at the posterior occiput. The acute terminal segment of the antenna is longer than the other segments and has 15 sensory spots (Gressitt, 1953).

The second instar can be distinguished by head capsule width and sometimes body size (Table 3-1). Other identifying features include the terminal segments of the antennae (shorter, less acute), the epicranial suture (more distinct), the node on the middle inner edge of the left mandible (distinctly tooth-like), the thoracic spiracle (broader, oval, non-distinct posterior margins, oval anterior-center tubercle) and rounder abdominal spiracles (Gressitt, 1953).

The third instar can be distinguished from early instars using head capsule width (Table 3-1). In addition, the terminal antennal segment of this instar is short and blunt with 17 sensory spots; the mandibles have complex molar areas; the pronotum is large, reddish brown and heavily sclerotized with approximately 18 dorsal and 50 bilateral pronotal bristles near the spiracles. The fifth abdominal tergite has approximately 250 short bristles on each side. The spiracles are large, rounded and sclerotized. The fecal pellet of the larva is flat, elliptical and approximately 8 mm long. The larval appearance varies

throughout development—shiny blue gray for the first 20 days and whitish for most of its stadium (Gressitt, 1953). The most recent detailed information on third instar morphology can be found in the literature (Bedford, 1974).

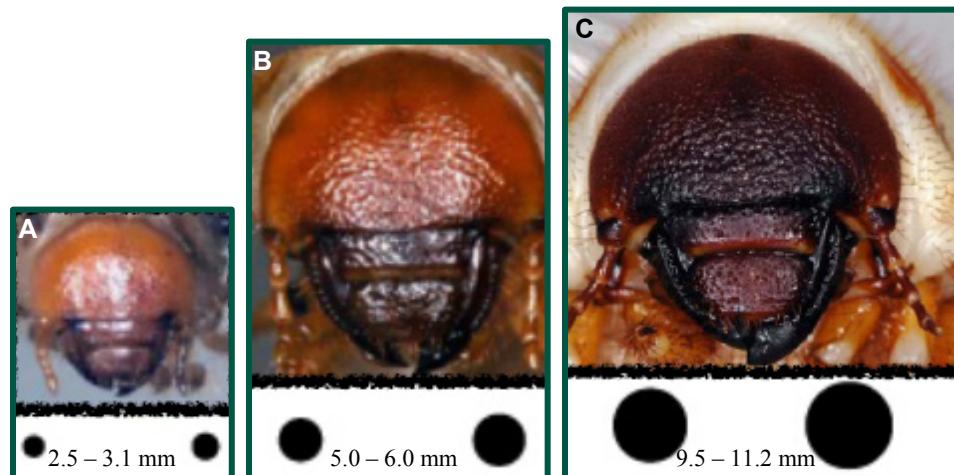


Figure 3-4 Head capsules of (A) first, (B) second and (C) third instars of *O. rhinoceros*; solid black circles below each image serve as scales to represent the range of head capsule size (photo courtesy of Aubrey Moore, University of Guam)

Pre-Pupa and Pupa

Prior to pupation, the larval body shrinks, and the body wall becomes more translucent. During this pre-pupal period, the body changes from whitish to creamy white. The pupa is yellowish brown, exarate, with a rubbery texture and characteristic odor. The sexes may be differentiated at this stage—the cephalic horns in males are approximately 3 times longer than wide, but only 1–2 times longer in females (Gressitt, 1953) (Figure 3-5).

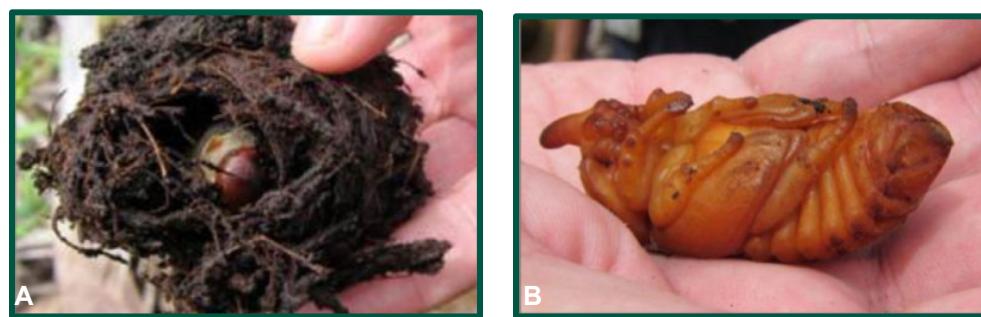


Figure 3-5 (A) Pre-pupa and (B) pupa of *O. rhinoceros* (photo courtesy of Arnold Hara, University of Hawaii)

Adult

Endrödi (1985) described morphological keys to distinguish *O. rhinoceros* adults from other congeneric species. Illustrations and descriptions of adult morphology

were also presented by Gressitt (1953). Adults have a convex reddish dark-brown to black elytra and a heavily sclerotized body (Gressitt, 1953). Adults vary in size, largely depending on larval nutrition ([Table 3-1](#)).

The compound eye is large and partly masked by a flange extending from the cephalic horn. The cephalic horn is 2.5–3 times longer than its base width in males, but shorter in females (Doane, 1913; Gressitt, 1953). The antenna is lamellate with 3 thick lobes forming the club ([Figure 3-6A](#)). The mouthparts are prominent and include the 4-segmented maxillary and 3-segmented labial palps (Gressitt, 1953).

The prothorax is typically one-third of the total body length and wider than long, tapering toward the concave anterior edge ([Figure 3-6A](#)). The thorax contains a single pair of spiracles located toward the dorsal edge of the prothoracic legs. The scutellum is triangular and blunt at the base; the thoracic sternum has large coxal cavities. The elytra extend from the mesothorax and cover the remaining dorsum (Garlovsky *et al.*, 1971; Gressitt, 1953). Adults are strong fliers with flight muscles that occupy most of the thoracic cavity (Monty, 1978). The hind wings have 9 prominent veins extending close to the posterior wing margin. The elytra protect the hind wings and have a smooth humerus; typically, the elytra have 6 rows of non-distinct punctures apically along the suture ([Figure 3-6B](#)). All 3 pairs of legs are stout, with sharp tibial spines that are adapted for burrowing (Gressitt, 1953; Monty, 1978). The fore tibia are larger than the hind tibia (Garlovsky *et al.*, 1971).

The abdomen contains 8 segments. The terga of the first 6 segments are pale and smooth, while the seventh is heavily sclerotized for stridulation with the posterior elytra (Gressitt, 1953). The distribution of pleural abdominal spiracles is also characteristic. The first 4 spiracles are large and elliptical, whereas the last 3 posterior pairs are smaller and broadly oval (Garlovsky *et al.*, 1971; Gressitt, 1953). In males, paramera are medium broad and narrow toward the wide apices (Endrödi, 1985). Mathur *et al.* (1960) described the internal and external genitalia of male and female *O. rhinoceros* specimens, and Jacob *et al.* (2008) further illustrated the structure and development of the male accessory sex glands. A ventral view of the thoracic segments and abdomen is presented in [Figure 3-6C](#).

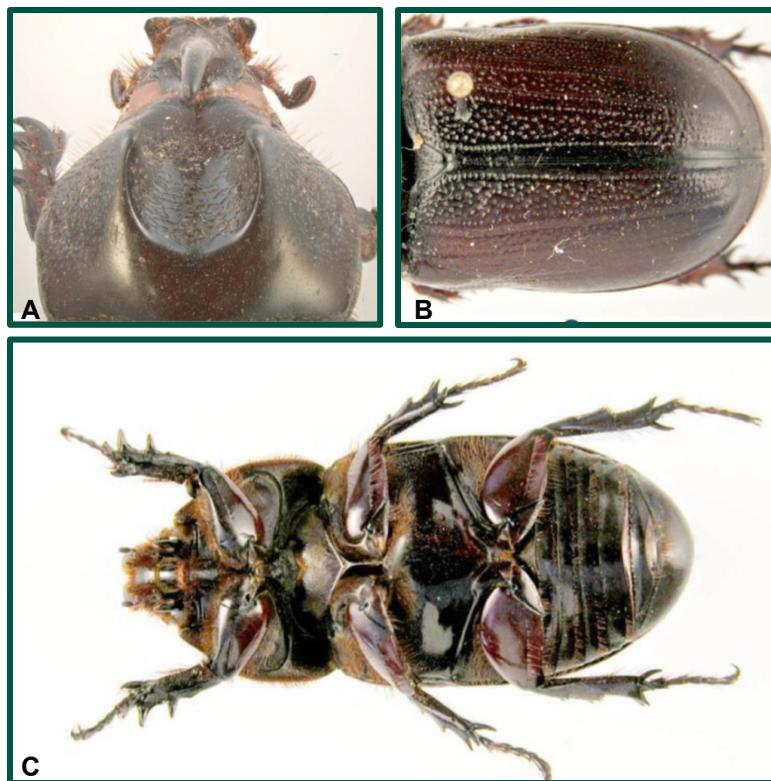


Figure 3-6 (A) Head with horn, antennae and fossorial forelegs; (B) punctures on elytra; (C) ventral view of the adult *O. rhinoceros* (photos courtesy of Pest and Diseases Image Library, Bugwood.org; numbers 5488589, 5488583, 5488582)

Males versus Females

Adult females have a blanket of long reddish erect hairs on the pointed pygidium, whereas adult males have a smooth, rounded and shiny pygidium with only a row of stout hairs along the ventral margin ([Figure 3-7](#)). Although male cephalic horns are typically longer than female, their size heavily depends on the environment; therefore, horn size may not be reliable for differentiating between the sexes (Garlovsky *et al.*, 1971; Gressitt, 1953).

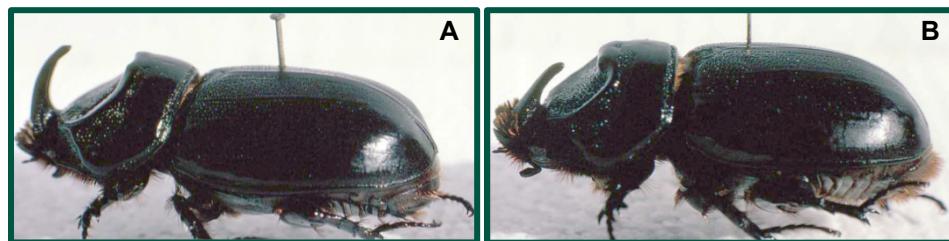


Figure 3-7 (A) Male and (B) female adult *O. rhinoceros* (images by Geoffrey Bedford printed with permission from the Annual Review of Entomology, volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

Young versus Mature

Newly emerged adults lack abrasions on the elytra and often have pupal exuviae or meconium. The young adults generally co-exist with third instars and pupae and have a strong odor (Gressitt, 1953; Zelazny, 1975). Mature females commonly have abrasions on their elytra and are often associated with eggs, forming galleries in wood and exhibiting a weak musky odor (Gressitt, 1953; Zelazny, 1975). Zelazny and Neville (1972) provided an age-endocuticle layer relationship to determine the ages of young adults, typically within the first 32 days of eclosion.

Diagnostics

Early instars of *O. rhinoceros* could not be distinguished from early instars of other scarab larvae. Therefore, the third instar is the ideal stage for identifying larval specimens during initial detection surveys. For rearing to this stage, place young larvae in a small container with 50:50 mixture of cowdung:rooted wood or sawdust with sufficient aeration, then transfer to the proper authority for identification (Bedford, 2014). The third instar morphology can be found in the literature (Bedford, 1974). Adults can be distinguished from congeneric species using the morphological keys provided by Endrödi (1985).

Similar Species

At present, 7 Oryctini species are found in North America: 5 *Strategus* spp. and 2 *Xyloryctes* spp. (Molet, 2014). Among the 39 species of *Oryctes* found globally, none are present in the contiguous U.S.; however, *O. rhinoceros* was recently reported in Hawaii (PestLens, 2014). Endrödi (1985) published detailed keys for the adults of 38 *Oryctes* spp. including *O. rhinoceros*.

Beaudoin-Ollivier *et al.* (1998, 2000) published simplified field keys to distinguish *O. rhinoceros* larvae from those of other species that feed on decaying organic matter. The study notes two characteristics that can identify the larva of *O. rhinoceros*—the presence of an impressed ring on the last abdominal segment and larvae that move on their side (Beaudoin-Ollivier *et al.*, 2000) ([Figure 3-8](#)). However, these methods may not prove useful in the case of congeneric species. Bedford (1974) described a complete set of morphological characteristics for accurately differentiating third instar *O. rhinoceros* from similar dynastid species.

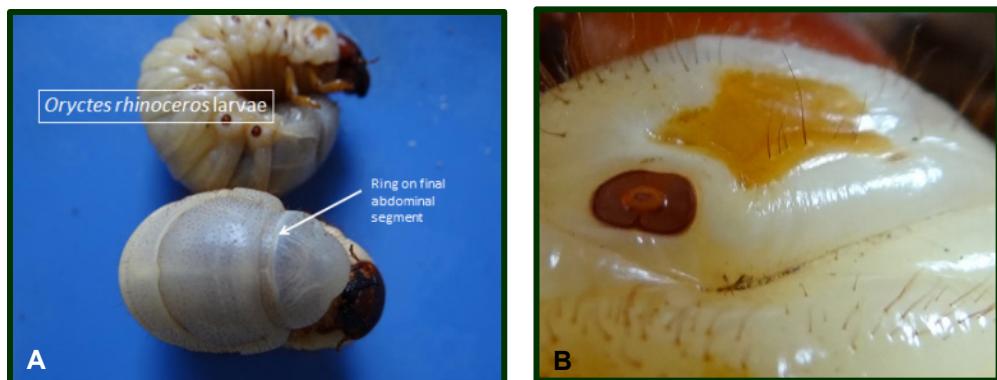


Figure 3-8 Simplified characteristics for identifying third instar *O. rhinoceros*: (A) impressed ring on the last abdominal segment and (B) pattern of hairs on first thoracic sclerite (images with permission from Trevor Jackson, based on the study by Beaudoin-Ollivier et al., 2000)

Biology

Life Cycle

The coconut rhinoceros beetle undergoes complete metamorphosis, passing through egg, larva, pupa and adult. The adult feeds on sap by tunneling into the crowns of palm trees and is the only damaging life stage. The immature stages feed on decaying vegetation and do not injure live plants.

Much of the *O. rhinoceros* life cycle takes place at breeding sites where all stages occur. Adults leave breeding sites to feed briefly on sap in the crowns of palm trees, but return to mate and oviposit (Moore, 2014f). The life cycle, beginning with breeding sites and extending to the adult stage, of the coconut rhinoceros beetle is summarized in [Figure 4-1](#). The duration of each stage presented in the diagram represents an average from the studies cited in the respective sections.

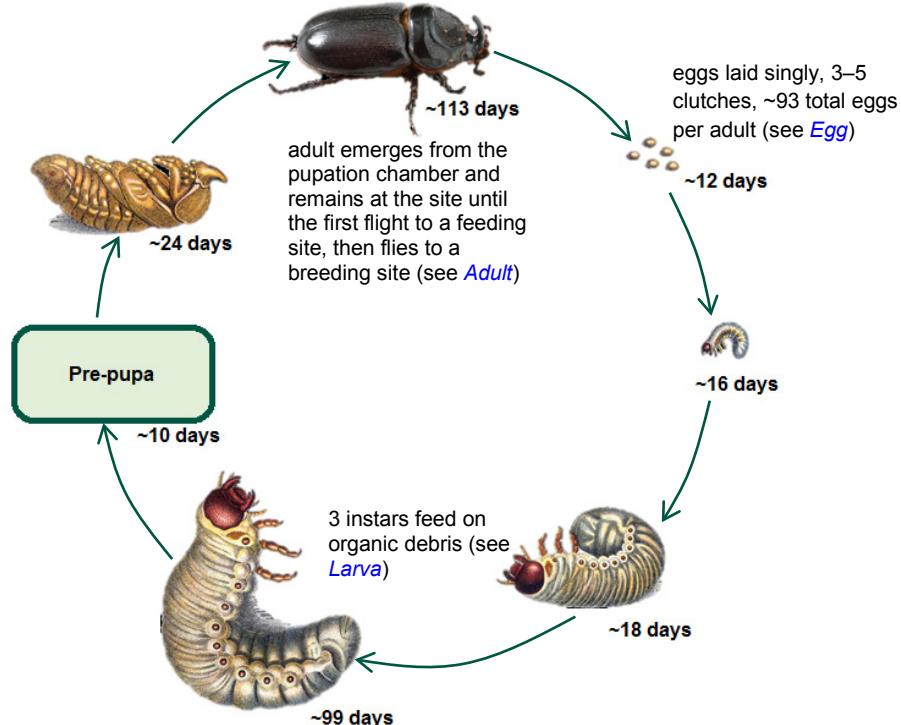


Figure 4-1 Life cycle of *O. rhinoceros* (adaptation of illustration included with permission from of Aubrey Moore, University of Guam)

Total Lifespan

The lifespan of the beetle appears to depend on substrate availability and seasonal variations at different locations (Cherian and Anantanarayanan, 1939; Gressitt, 1953; Hinckley, 1973; Jacob and Bhumannavar, 1991; Lever, 1969; Sushil and Mukhtar, 2005). The total lifespan generally ranges from 4–10 months, allowing for more than 1 generation/year. In Palau, which is tropical without distinct seasons, the lifespan was approximately 7 months, and under favorable conditions, the insect may have up to 3 generations per year (Gressitt, 1953). In India and China, the lifespan of *O. rhinoceros* varied from 3–9 months (Cherian and Anantanarayanan, 1939; Gressitt, 1953). In Samoa, Hinckley (1973) observed that under favorable conditions, the egg-to-egg generation time was below 5 months.

Eggs and Breeding Sites

After finding a favorable breeding site, the female adult burrows into the substrate to lay eggs (Vargo, 1995). On average, oviposition begins within a month of copulation (Gressitt, 1953; Hurpin and Fresneau, 1973; Sushil and Mukhtar, 2005; Zelazny, 1975). The egg stage lasts approximately 12 days with the typical female laying 4–5 eggs/day singly in the substrate; however, under favorable conditions females may lay 10–14 eggs/day (Bedford, 1976b; Gressitt, 1953; Hinckley, 1973). Depending upon the adult size, eggs are laid in 3–5 clutches of 27–38 eggs/clutch with 20 days between clutches (Gressitt, 1953; Hinckley, 1973). The oviposition rate varies based on adult longevity; adults lay 93 eggs on average in their lifetimes. Moreover, the oviposition location within a substrate can differ, including the fibrous apex of dead standing palms or under the loose bark of decaying coconut logs. In recently killed palms with no decay, the beetle may oviposit singly in small balls of shredded wood constructed during burrowing (Monty, 1978). Hinckley (1973) noted that the adult female chewed through the palm host in a serpentine fashion, ovipositing as it tunneled and subsequently compressing the shredded wood behind it to protect each egg. The number of eggs and reproductive days can vary significantly between individuals and may depend on adult longevity and oviposition substrate (Catley, 1969; Hurpin and Fresneau, 1973). Most adults continue to lay eggs 7–14 days prior to death (Hurpin and Fresneau, 1973). Males and females generally co-occur at the breeding sites. The females typically arrive first and oviposit; the males then arrive, lingering at the site to chew and prepare additional substrate for the emerging larvae (Zelazny and Alfiler, 1991).

Dead standing palms, logs and stumps are the preferred breeding sites (Bedford, 1976b; Catley, 1969; Gressitt, 1953). Common breeding sites are presented in [Table 4-1](#) and [Figure 4-2](#).

Table 4-1 Coconut rhinoceros beetle breeding sites

Breeding substrates	Reference
dead standing palms ¹	Bedford (1976b), Gressitt (1953)
palm logs ¹	Catley (1969), Gressitt (1953)
short coconut stumps ¹	Gressitt (1953)
cowdung ¹	Lever (1969)
compost ¹	Gressitt (1953)
sawdust pits or heaps ¹	Zelazny (1975)
oil palm mesocarp ¹	Ponnamma <i>et al.</i> (2001)
oil palm bunch refuse	Jacob and Bhumannavar (1991)
empty oil palm fruit bunches	Wan Zaki <i>et al.</i> (2009)
dried fronds and shredded palm wood refuse	Bedford (2013a), Monty (1978)
wood bark	Jacob and Bhumannavar (1991)
miscellaneous wood	Gressitt (1953)
soil underneath palm logs	Gressitt (1953)
papaya skin and taro refuse	Gressitt (1953)
humus from decaying cocoa pods	Bedford (1976b)
decaying coir refuse	Cherian and Anantanarayanan (1939)
sugarcane bagasse	Cherian and Anantanarayanan (1939)
sugarcane leaves preserved for silage	Monty (1978)
filter cakes from sugarcane processing plants	Monty (1978)
decaying rice straw heaps	Jacob and Bhumannavar (1991)
debris lodged near coconut fronds (rare)	Moore (2011, 2012a)
heaps of decaying organic matter	Beaudoin-Ollivier <i>et al.</i> (2000), Monty (1978)

¹ Preferred breeding sites

The beetles can survive in forests with available live and felled hosts (Cumber, 1957; Gressitt, 1953). Other substrates favored by the larvae include the decaying wood of *Pandanus* spp. (screwpine), *Artocarpus* spp. (breadfruit), *Casuarina* spp., *Calophyllum inophyllum* L. (Alexandrian laurel), *Dictyosperma album* (Bory) Scheff. and *Mangifera* spp. (mango) (Gressitt, 1953; Monty, 1978).



Figure 4-2 Breeding substrates: (A) standing palm killed by *O. rhinoceros* in Tumon Bay, Guam; (B) cross-section exhibiting feeding activity; (C) larvae extracted from substrate; (D) larvae inside rotten felled logs; (E, F) palm residue as potential substrate; (G) potential substrate for arboreal development; (H) sawdust substrate; (I) potential breeding site created by hurricane damage in Fiji (photos courtesy of Aubrey Moore, University of Guam [A, B, D, E, G, H]; Arnold Hara, University of Hawaii [F]; images by Geoffrey Bedford printed with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org> [C, I])

Larvae

Instars

The 3 instars each molt following a brief period of inactivity. Larval development varies with the season and breeding medium (Bedford, 1976b; Catley, 1969; Cherian and Anantanarayanan, 1939; Gressitt, 1953; Indiravathi *et al.*, 2001; Monty, 1978; Sushil and Mukhtar, 2005; Vargo, 1995; Zhong *et al.*, 2013). The development of the first, second and third instars require 16, 18 and 99 days, respectively with the development periods possibly overlapping (Gressitt, 1953). In Malaysia, Wan Zaki *et al.* (2009) reported a

predominant number of second (40% of all stages) and third instars (36%) co-existing in empty oil palm fruit bunches. At high insect densities, the instars and newly eclosed adults often co-exist at the breeding site (Gressitt, 1953).

Feeding Behavior

Immediately after hatching, the larva feeds on its egg chorion, frass or host remains left by the adults during tunneling and oviposition (Vargo, 1995). If oviposition occurs near the core of a decaying trunk, the larva feeds outward toward the bark (Gressitt, 1953). At high densities, the larvae can reduce the infested trunk to crumbled fibers, larval frass and decaying tissue (Monty, 1978). Larvae avoid extremely hard regions of the trunk becoming concentrated under the palm bark, at the decaying ends or in the center of the trunk where the tissue is softer (Bedford, 1976b; Gressitt, 1953). Although larvae typically avoid damp wood, they can survive submersion in seawater for more than 48 hours (Gressitt, 1953; Nirula *et al.*, 1952). If mortality factors are limited, a single dead standing trunk can hold more than 200 larvae (Monty, 1978). In breeding sites with low nutritional value and in dense logs, mortality may approach 100% before adulthood (Hinckley, 1973). Refer to [Eggs and Breeding Sites](#) for information on feeding substrates.

Movement

Studies under natural conditions suggest that larvae exhibit negative phototaxis, possibly to avoid desiccation and/or natural enemies (Bedford, 1980). Larvae are cryptic and hide in the breeding substrate until developing into adults (Bedford, 2013a). In Guam, a survey of the vertical distribution of adults and larvae in dead standing palms suggested that most individuals were found 3.4–4.3 m from the base (Moore, 2011). The larvae can survive temperatures between 16 and 49 °C (Jacob and Bhumannavar, 1991; Nirula *et al.*, 1952); however, the optimum development temperature is 27–29 °C with a relative humidity reaching 85–95% (Bedford, 1980). A field study by Moore and Quitugua (2009) demonstrated that larvae and adults survived high temperatures (40–59 °C) in rotting palm residue covered with plastic sheets. In a preliminary laboratory study using steer manure, Moore (2014b) demonstrated a lethal temperature, $LTe_{50} \approx 47$ °C (over 24 hours), for third instars, with the compost heap temperatures reaching to 70 °C (Gressitt, 1953; Zimmermann, 1982). The larvae survive unfavorable conditions by avoiding ‘hotspots’ in which temperatures exceed 37 °C (El-Shafie, 2014).

Unfavorable environmental conditions reduce larval size and prolong development up to 420 days (Catley, 1969). Zelazny and Alfiler (1986) reported rainfall as a factor in larval mortality; mortality can also occur through desiccation, unavailability of a suitable pupation site or overcrowding

(Cherian and Anantanarayanan, 1939). During active feeding, larval movement within a breeding substrate can be influenced by environmental factors. In a farmyard manure substrate, the larvae are typically found 5–30 cm below the surface where early instars often die if the substrate dries out, but third instars can burrow deeper into the moist soil to avoid desiccation (Cherian and Anantanarayanan, 1939). Larval activity and movement may also depend on the breeding substrate. For example, the larva typically moves only a few centimeters in solid wood, but movement increases in sawdust or compost. The instars utilize different mechanisms to move on a flat surface: young larvae may use their thoracic legs, while mature larvae typically move by contracting and relaxing body segments (Gressitt, 1953). After feeding, the larvae find a favorable site for pupation.

Pre-Pupa and Pupa

After feeding, the third instar searches for a suitable pupation site, preferably a compact location within the same substrate. However, if the current media is not firm, the larva moves to a different substrate. For example, if the breeding site is a decaying coconut log, the third instar might tunnel into a dense portion of the wood and construct a pupation chamber away from the hollow bark, rotten core or tips (Catley, 1969; Gressitt, 1953). Similarly, if the soil below is more compact than the breeding substrate, the larva burrows away from the current substrate and into the soil (Gressitt, 1953). In manure, the pupal chamber is typically found 15–30 cm deep in the soil near the breeding site (Cherian and Anantanarayanan, 1939). In sawdust, the pupal cell may occur further below the surface (1–1.5 m) (Catley, 1969; Gressitt, 1953; Vargo, 1995). In soil or other non-firm breeding substrates, *O. rhinoceros* constructs an ovoid pupal cell with thick walls ($5.5 \times 3.5 \times 3.3$ cm) using debris and liquid excretions (Gressitt, 1953; Lever, 1969). The pupating larva produces large quantities of liquid from its mouth and semi-solid excrement through its anal opening. After applying the liquid excrements, the larva turns inside the chamber to smooth the inside walls (Cherian and Anantanarayanan, 1939). The entrance of the pupal chamber is covered with loose substrate or frass (Gressitt, 1953). If no soil is available, the larva constructs irregular chambers using fibers and leaves (Monty, 1978). After preparing the chamber, the larva undergoes a brief inactive pre-pupal phase to prepare for pupation. The larva then empties the alimentary canal, becoming flaccid and changing in appearance from off-white or bluish gray to creamy or pinkish white (Bedford, 1980; Catley, 1969; Gressitt, 1953; Monty, 1978). The pupa is exarate and is yellowish brown (Monty, 1978). The development periods of the pre-pupa (~10 days) and pupa (~24 days) vary with location (Bedford, 1976b; Catley, 1969; Cherian and Anantanarayanan, 1939; Gressitt, 1953; Indiravathi *et al.*, 2001; Monty, 1978; Sushil and Mukhtar, 2005; Vargo, 1995; Zhong *et al.*, 2013).

Adults

Before First Flight

After eclosion to adulthood, the insect remains inside the pupal chamber for 10–24 days (Cherian and Anantanarayanan, 1939; Gressitt, 1953; Lever, 1969; Sushil and Mukhtar, 2005; Vander Meer, 1987; Zelazny and Alfiler, 1987) and, upon emergence from the pupal chamber, remains at the site of pupation for 20–30 days (Jacob and Bhumannavar, 1991; Vander Meer, 1987; Zelazny and Alfiler, 1987). Immediately after emergence, the adult is whitish, but completes pigmentation within the next 24 hours. The cuticle is gradually sclerotized (Gressitt, 1953; Zelazny, 1975).

First Flight, First Feeding, Breeding and Later Feeding

Both males and females fly within approximately 20 days of adult emergence; the youngest adults found near the palm crowns are 20–30 days old (Zelazny, 1975). A Philippine field study demonstrated that the adult beetles continue to feed for approximately 35 days at their first feeding site then occasionally disperse over long distances. After the first feeding, the adults proceed to the breeding site where they remain for 32–49 days. After oviposition, the adults continue to visit additional host plants for a shorter late-life feeding lasting approximately 14 days (Vander Meer, 1987; Zelazny and Alfiler, 1987, 1991).

Survival

Adults prefer temperatures between 28–30 °C and typically occur at elevations below 900 m (Gressitt, 1953; Hurpin and Fresneau, 1973). Females tend to survive longer than males (Bedford, 1976b; Hurpin and Fresneau, 1973). Without other mortality factors, adult longevity can be predicted using the adult weight at the time of eclosion from the pupa: an adult dies when its body weight reaches approximately 40% of its initial value (Vander Meer, 1987). In a laboratory study, Indiravathi (2001) reported that approximately 63% of eggs and 87% of larvae successfully develop into adults. Another study examined the biology of the beetle in manure pits and reported 83–91% adult emergence from the pupal chamber (Sushil and Mukhtar, 2005). On average, studies indicate an adult longevity of approximately 113 days (Bedford, 1976b; Catley, 1969; Cumber, 1957; Gressitt, 1953; Hurpin and Fresneau, 1973; Indiravathi *et al.*, 2001; Jacob and Bhumannavar, 1991; Lever, 1969; Sushil and Mukhtar, 2005; Vander Meer, 1987; Zelazny and Alfiler, 1987).

Mating

Mating primarily occurs at night after the first flight and feeding. Dead coconut trunks and other breeding substrates are the reported mating sites for the beetle (Cumber, 1957; Zelazny, 1975). Although copulation may occur near feeding locations including palm crowns and leaf axils, to date, no peer-reviewed reports describe these events (Bedford, 2013a, 2014). Multiple matings (~8) may occur in the field, but are not essential because the female can store sperm in a spermatheca after a single mating. Sperm is typically viable for 4–6 months (Catley, 1969; Hurpin and Fresneau, 1973). The male to female ratio is typically 1:1 (Indiravathi *et al.*, 2001), but may sometimes vary from 1:0.65 to 1:3.27 (Al-Habshi *et al.*, 2006; Bedford, 1975; Gressitt, 1953; Hinckley, 1973; Jacob and Bhumannavar, 1991; Sushil and Mukhtar, 2005; Zhong *et al.*, 2013).

Adult Hosts

Oryctes rhinoceros adults reportedly feed on approximately 51 plant species from 10 families ([Table 4-2](#)). Thirty-seven of the reported host species belong to the palm family, Arecaceae. The coconut palm is the preferred host, followed by oil and date palms (Catley, 1969; Gressitt, 1953).

A list of plant hosts reported only under laboratory conditions is presented in [Table 4-3](#). The scientific names, synonyms and common names for each plant host were retrieved from the following databases: Plants Database (USDA and NRCS, 2014), Catalogue of Life (Roskov *et al.*, 2014), Crop Protection Compendium (CABI, 2014a) and The Plant List (2013).

Table 4-2 Reported plant hosts of *O. rhinoceros*

Scientific name	Common name	References
Agavaceae		
<i>Agave</i> spp.		Cherian and Anantanarayanan (1939)
<i>Agave americana</i> L.	American century plant	Gressitt (1953)
<i>Agave sisalana</i> Perrine	sisal hemp	Gressitt (1953), Chong <i>et al.</i> (1991)
Aloaceae		
<i>Aloe</i> spp.	aloe	Sivakumar and Mohan (2013)
Araceae		
<i>Colocasia</i> spp.	colocasia	Gressitt (1953)
<i>Alocasia</i> spp.	taro	Gressitt (1953)
<i>Cyrtosperma</i> spp.		Gressitt (1953)
<i>Xanthosoma</i> spp.	elephant's ear	Gressitt (1953)

Aracaceae		
<i>Acanthophoenix rubra</i> (Bory) H. Wendl.	barbel palm	Gressitt (1953)
<i>Aiphanes horrida</i> (Jacq.) Burret (= <i>A. caryotifolia</i>)	ruffle palm, coyure palm	Gressitt (1953)
<i>Areca</i> spp.		Lever (1969)
<i>Areca catechu</i> L. (= <i>A. cathecu</i>) ¹	betel palm	Nirula et al. (1952), Gressitt (1953)
<i>Arenga</i> spp.		Lever (1969)
<i>Arenga pinnata</i> (Wurmb) Merr. ¹	sugar palm	Gressitt (1953)
<i>Borassus</i> spp.		Lever (1969)
<i>Borassus flabellifer</i> L.	toddy palm, palmyra palm	Nirula et al. (1952), Gressitt (1953)
<i>Caryota urens</i> L.	jaggery palm	Gressitt (1953)
<i>Clinostigma samoense</i> H. Wendl. (= <i>Cyphokentia samoensis</i>)		Gressitt (1953)
<i>Cocos nucifera</i> L. ¹	coconut	Bedford (1980), Gressitt (1953), Lever (1969), Nirula et al. (1952)
<i>Corypha</i> spp.		Lever (1969)
<i>Corypha umbraculifera</i> L.	talipot palm	Cherian and Anantanarayanan (1939), Nirula et al. (1952)
<i>Corypha utan</i> Lam. (= <i>C. elata</i>)	gebang palm, serdang palm	Gressitt (1953)
<i>Dictyosperma album</i> (Bory) Scheff.	hurricane palm, red palm	Gressitt (1953)
<i>Dypsis pinnatifrons</i> Mart. (= <i>D. gracilis</i>)	dypsis palm	Gressitt (1953)
<i>Elaeis</i> spp. ¹	oil palm	Chong et al. (1991), Kamarudin and Wahid (1997), Lever (1969)
<i>Elaeis guineensis</i> Jacq. ¹	African oil palm	Gressitt (1953), Hoyt (1963), Bedford (1980), Sullivan et al. (2013)
<i>Heterospathe elata</i> var. <i>palauensis</i> (Becc.) Becc.		Gressitt (1953)
<i>Hydriastele palauensis</i> (Becc.) W.J. Baker & Loo (= <i>Gulubiopsis palauensis</i>)		Gressitt (1953)
<i>Latania</i> spp.		Gressitt (1953)
<i>Livistona</i> spp.		Lever (1969)
<i>Livistona chinensis</i> (Jacq.) R.Br. ex Mart.	fountain palm, latanier palm	Gressitt (1953), Bedford (1980), Monty (1978)
<i>Hyophorbe lagenicaulis</i> (L.H. Bailey) H.E. Moore (= <i>Mascarena lagenicaulis</i>)	bottle palm	Gressitt (1953)
<i>Metroxylon</i> spp.		Lever (1969)
<i>Metroxylon amicarum</i> (H. Wendl.) Hook. f. (= <i>Coelococcus carolinensis</i>)	caroline ivory nutpalm	Gressitt (1953)
<i>Metroxylon sagu</i> Rottb.	sago palm	Gressitt (1953)
<i>Metroxylon vitiense</i> (H. Wendl.) Hook. f.		Pacific Islands Pest List Database (2009)
<i>Normanbya normanbyi</i> (W. Hill) L.H. Bailey	black palm	Gressitt (1953)
<i>Nypa</i> spp.		Lever (1969)

<i>Nypa fruticans</i> Wurmb	nipa palm	Gressitt (1953), Nirula et al. (1952)
<i>Oncosperma</i> spp.		Gressitt (1953)
<i>Oncosperma tigillarium</i> (Jack) Ridl.	niblong palm	Nirula et al. (1952)
<i>Phoenix</i> spp.		Lever (1969)
<i>Phoenix dactylifera</i> L.	date palm	Gressitt (1953), El-Shafie (2014)
<i>Phoenix sylvestris</i> (L.) Roxb.	wild date palm	Gressitt (1953), Nirula et al. (1952)
<i>Pinanga insignis</i> Becc. (= <i>Pseudopinanga insignis</i>)		Gressitt (1953)
<i>Pinanga</i> spp.		Gressitt (1953)
<i>Pritchardia pacifica</i> Seem. & H. Wendl.	Fiji fan palm	Gressitt (1953)
<i>Raphia farinifera</i> (Gaertn.) Hyl. (= <i>R. ruffia</i>) ¹	raffia palm	Bedford (1980), Monty (1978), Hoyt (1963)
<i>Raphia vinifera</i> P. Beauv.	West African piassava palm	Gressitt (1953)
<i>Roystonea regia</i> (Kunth) O.F. Cook (= <i>R. elata</i> , <i>Oreodoxa regia</i>)	royal palm	Gressitt (1953), Bedford (1980)
<i>Stevensonia</i> spp.		Gressitt (1953)
<i>Syagrus romanzoffiana</i> (Cham.) Glassman (= <i>Arecastrum plumosa</i>)	queen palm	Gressitt (1953)
<i>Thrinax</i> spp. (thatch palm)		Gressitt (1953)
<i>Verschaffeltia splendida</i> H. Wendl.	Latanier Latte	Gressitt (1953), Monty (1978)
<i>Wodyetia bifurcata</i> A.K. Irvine	foxtail palm	USDA-APHIS EPICA (2009)
Bromeliaceae		
<i>Ananas comosus</i> (L.) Merr.	pineapple	Nirula et al. (1952), Gressitt (1953), Chong et al. (1991)
Caricaceae		
<i>Carica papaya</i> L.	papaya	Catley (1969), Chong et al. (1991)
Cyatheaceae		
<i>Cyathea</i> spp.	treefern	Gressitt (1953)
Liliaceae		
<i>Musa</i> spp.	banana	Gressitt (1953), Sharma and Gupta (1988), Chong et al. (1991), Sivakumar and Mohan (2013)
Pandanaceae		
<i>Pandanus</i> spp.		Gressitt (1953), Lever (1969)
<i>Pandanus tectorius</i> Parkinson ex Du Roi	Tahitian screwpine	Gressitt (1953)
Poaceae		
<i>Saccharum</i> spp.	sugarcane	Gressitt (1953), Chong et al. (1991), Sivakumar and Mohan (2013)
Sterculiaceae		
<i>Theobroma cacao</i> L.	cacao	Pacific Islands Pest List Database (2009)

¹ Preferred host

Table 4-3 Plant hosts of *O. rhinoceros* reported only under laboratory conditions (Gressitt, 1953)

Plant Host	Common name
<i>Colocasia esculenta</i> (L.) Schott	coco yam
<i>Alocasia macrorrhizos</i> (L.)	giant taro
<i>Cyrtosperma merkusii</i> (Hassk.) Schott (= <i>C. chamissonis</i>)	swamp taro
<i>Xanthosoma sagittifolium</i> (L.) Schott	arrowleaf elephant's ear
<i>Tradescantia spathacea</i> Sw. (= <i>Rhoeo discolor</i>)	boatlily
<i>Hanguana malayana</i> (Jack) Merr.	
<i>Persea americana</i> Mill.	avocado
<i>Cordyline fruticosa</i> (L.) A. Chev. (= <i>C. terminalis</i>)	tiplant
<i>Dracaena angustifolia</i> (Medik.) Roxb.	
<i>Hymenocallis littoralis</i> (Jacq.) Salisb.	beach spiderlily
<i>Tacca leontopetaloides</i> (L.) Kuntze	batflower

Other hosts are not attacked if coconut palms are abundant, depending on the developmental stage of the host (Cherian and Anantanarayanan, 1939). For example, *O. rhinoceros* adults do not damage *Pandanus tectorius* Parkinson ex Du Roi if mature coconut palms are available; however, adults prefer *P. tectorius* to young coconut palms.

Although *Lantana* spp. are listed as hosts in the Crop Protection Compendium and in publications citing CABI (2014b), no supporting information confirms this association, which possibly confuses *Lantana* spp. with *Latania* spp., a host of *O. rhinoceros* in Palau (Gressitt, 1953). *Casuarina equisetifolia* L. has been erroneously reported as a minor adult host, but the original citation includes the plant as a larval host (Elfers, 1988). For information regarding larval hosts, refer to *Eggs and Breeding Sites* on page 4-2.

Natural Dispersal

Active Flight

Long-distance flight by adults is possible under adverse conditions but short flights appear preferred if breeding and feeding sites are available at the location of origin. Most flight is observed at dusk and dawn (Catley, 1969). In a field study, Kamarudin and Wahid (2004) demonstrated that adults move 10–23 m/day and up to 1.3 km/week. A laboratory study demonstrated that palm-fed tethered adult beetles had a flight potential of 2–3 hours, covering the equivalent of 2–4 km (Hinckley, 1973). Other 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 have been recaptured at 900 m within 3 days and approximately 1600 m within a month (Cumber, 1957). Flight may occur during different seasons depending on location. In Samoa, numerous adults were

captured in flight from February–June, whereas in southern India, adult beetles were abundant from March–April (Cherian and Anantanarayanan, 1939; Cumber, 1957).

Natural Movement of Breeding Substrates

Coconut palms grow along ocean shores in many locations. After infestation, some decaying palm logs may travel short distances through the sea. Larvae may survive inside the infested substrate and reach other locations aided by the ocean currents (Gressitt, 1953; Lever, 1969).

Human-Assisted Spread

Cargo such as timber, sawdust and copra are suitable larval substrates; ships carrying infested materials can introduce *O. rhinoceros* in new locations (Gressitt, 1953; Stride, 1977). However, port interceptions and previous reports indicate that the most likely method of introduction occurs through adults that hitchhike aboard ships and planes. Early coconut rhinoceros beetle invasions in the Pacific islands most likely occurred through sea and air traffic during WWII (Catley, 1969; Nishida and Evenhuis, 2000). The beetles are active fliers at night, and containers loaded after sunset are more likely to have hitchhiking adults than those loaded during the daytime. Regulatory personnel have found beetles in empty pallets on shipments from Guam to continental North America (CRB TWG, 2014). Moore (2014f) noted that in Guam soil bags high in organic content and stored outside (common in hardware stores) are frequently infested with *O. rhinoceros* larvae. Adults are occasionally reported in the beds of pickup trucks (Moore, 2014f).

After introduction, movement or availability of the substrates can rapidly spread the beetles to uninfested locations (Gressitt, 1953; Guaminsects.net, 2007b; Sweeney, 2008). In Oman, the percentage of infestation doubled when infested cattle manure was transported to meet the demands of increasing banana cultivation (Kinawy, 2004). In addition to the unintentional movement of infested substrates, the beetles may have been deliberately moved due to a perceived potential for nutrition, collection and cultural amusement (Fakayode and Ugwumba, 2013; New, 2005; Okaraonye and Ikewuchi, 2009; Onyeike *et al.*, 2005; Ratcliffe, 2006). A lack of public awareness may be a key factor in the spread of this insect (Ridgell, 2009).

Geographic Distribution

Ecological Distribution

Oryctes rhinoceros is endemic to southern and Southeast Asia including Bangladesh, China, India, Sri Lanka, Taiwan, Indonesia, Malaysia, the Philippines and Thailand ([Table 4-4](#)). Although the exact origin of the pest is unknown, reports date back to the 1890s' from southern India and Malaysia (Alam, 1975; Cherian and Anantanarayanan, 1939; Gressitt, 1953; Nirula *et al.*, 1952). The pest is suspected to have spread from Malaysia to southern Myanmar and then north. In Polynesia, the insect was likely introduced to Samoa from Sri Lanka through the import of rubber seedlings. The pest further spread to American Samoa, Niue, Keppel Island, Tonga, Wallis and Tokelau. The beetle was eradicated from Tonga in the 1930s, but was re-introduced during WWII (Catley, 1969; Pacific Islands Pest List Database, 2009). In Africa, the beetle is present in Mauritius and Réunion (Catley, 1969; Lever, 1969; Monty, 1978; Nirula *et al.*, 1952). Although Nirula *et al.* (1952) and Hoyt (1963) published sightings of *O. rhinoceros* in Burundi, Rwanda, Tanganyika, Sierra Leone and Nigeria, these reports likely reflect a mistaken identification for the endemic *O. monoceros* (Bedford, 2014; Gressitt, 1953; Jackson, 2014). In Micronesia, the pest was reported in Palau. In 2006, a single adult *O. rhinoceros* was caught in a Saipan seaport warehouse, but the insect is not known to be established at this location. In the U.S., the only reports of *O. rhinoceros* have occurred in Guam (11 September 2007) and Hawaii (23 December 2013). In Hawaii, the insect was first reported on Oahu at the Joint Base Pearl Harbor-Hickam (JBPHH) and initially contained within a 3-km radius of the first detection. However, adults were later found outside this radius, further extending the delimiting buffer zone by ~3 km in all directions (Hawaii Department of Agriculture, 2014e; Hawaii Invasive Species Council, 2014b, 2014h). The worldwide distribution of *O. rhinoceros* is presented in [Figure 4-3](#).

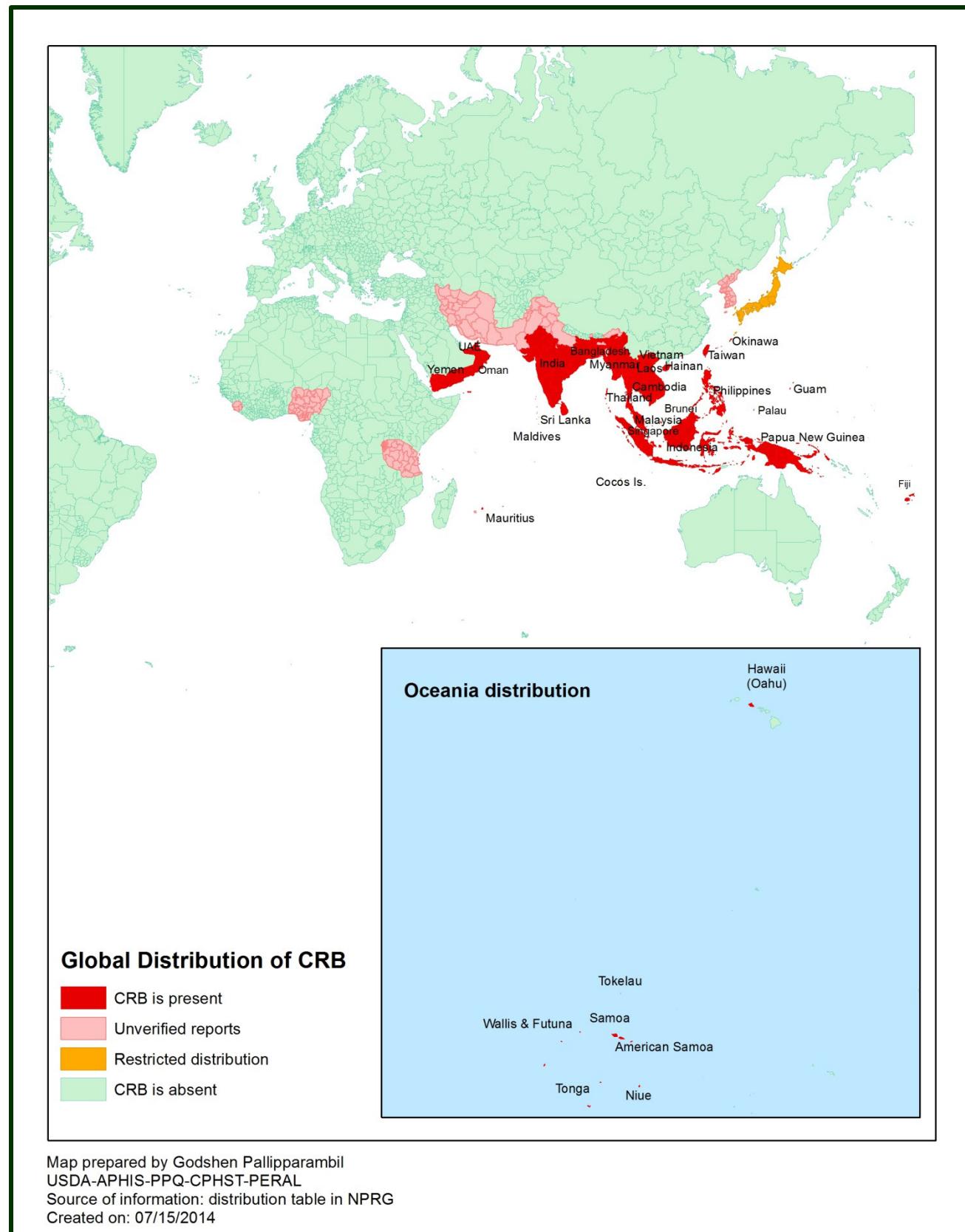


Figure 4-3 Worldwide *O. rhinoceros* distribution; beetle confirmed in (A) native locations with immediate spread and (B) introductions on Oceania islands closer to the U.S. Refer to Table 4-4 for further information.

Table 4-4 Worldwide distribution of *O. rhinoceros*

Location	Specific locations (if available)	References
Africa		
Burundi, Rwanda, and Tanganyika ³		Nirula <i>et al.</i> (1952)
Sierra Leone ³		Hoyt (1963)
Mauritius		Catley (1969), Lever (1969)
Nigeria ³		Hoyt (1963)
Réunion		Monty (1978)
Asia		
the Andaman and Nicobar islands		Catley (1969), Jacob and Bhumannavar (1991), GBIF (2014)
Bangladesh		Alam (1975)
Brunei		Waterhouse (1993)
Cambodia		Waterhouse (1993)
China ¹	Hainan Province	Gressitt (1953), Lin <i>et al.</i> (2010)
Cocos (Keeling)		Catley (1969)
Diego Garcia ²		Catley (1969)
Hong Kong ¹		Gressitt (1953)
India ¹	Kerala, Karnataka, Tamil Nadu, West Bengal, Maharashtra, Orissa, Madhya Pradesh, Assam, Rajasthan, Manipur, Goa, Nagaland, Andhra Pradesh, Gujarat, Bihar, Jharkhand and Tripura	Cherian and Anantanarayanan (1939), Nirula <i>et al.</i> (1952), Bhatnagar (1971), Gope and Prasad (1983), Raju (1983), Sharma and Gupta (1988), Dhileepan (1991), Singh and Gandhi (2010), Coconut Development Board (2013)
Indonesia ¹	Pekalongan, Irian Jaya, Kalimantan, Maluku, Nusa Tenggara, Sulawesi, Sumatra, Mattirobulu, Kabupaten Pinrang, central Java, West Java Regency, Moluccas, Bangka and Mt. Dempo	Muir and Swezey (1916), Gressitt (1953), PQR EPPO (2013), Daud (2007), GBIF (2014)
Iran		Bedford (2013a), PQR EPPO (2013)
Japan	Ryukyu, ¹ Yaeyama, Okinawa	PQR EPPO (2013), Gressitt (1953), Hosoya (2011), GBIF (2014)
Korea		Gressitt (1953), Endrödi (1985)
Lakshadweep		Mohan and Pillai (1993e)
Laos		Waterhouse (1993)
Malaysia ¹		Gressitt (1953), Waterhouse (1993), Darus and Basri (2000)
the Maldives		Zelazny <i>et al.</i> (1990)
Myanmar ¹		Nirula <i>et al.</i> (1952), Gressitt (1953), Bedford (1980)
Oman		Kinawy (2004)
Pakistan ³	western Pakistan	Gressitt (1953), Crawford (1981)
the Philippines ¹		Nirula <i>et al.</i> (1952), Gressitt (1953), Zelazny and Alfiler (1987), GBIF (2014)

Singapore		Cherian and Anantanarayanan (1939), GBIF (2014)
Sri Lanka ¹		Nirula <i>et al.</i> (1952), Gressitt (1953), GBIF (2014)
Taiwan ¹		Gressitt (1953), GBIF (2014)
Thailand ¹		Gressitt (1953), GBIF (2014)
United Arab Emirates ²		Gassouma (2004)
Vietnam ¹		Bedford (1980), Waterhouse (1993)
Yemen		Al-Habshi <i>et al.</i> (2006), El-Shafie (2014)
North America		
Hawaii ²	first detected on 23 December 2013 on Oahu at the Joint Base Pearl Harbor-Hickam; ongoing eradication	Hawaii Department of Agriculture (2014e)
Oceania		
Fiji ²		Catley (1969), Gressitt (1953), Bedford (1980), Young (1986)
Guam ²		USDA-APHIS EPICA (2007), Sweeney (2008), Moore (2012a)
Niue ²		Dharmaraju (1980)
Palau ²		Gressitt (1953), Catley (1969), Muniappan (2002)
Papua New Guinea ²		Gressitt (1953), Bedford (1976b)
Samoa ²		Bedford (1980), Cumber (1957), Catley (1969)
American Samoa ²		Monty (1978), Catley (1969), Pacific Islands Pest List Database (2009)
Tokara ²		Hosoya (2011)
Tokelau ²		Catley (1969), Uili (1980)
Tonga ²		Catley (1969)
Wallis ²		Cohic (1950)

¹presumed native; ²introduced; ³unverified

Potential Distribution

Among other factors, the distribution of *O. rhinoceros* depends on adult host availability, breeding substrate abundance and favorable abiotic factors. The optimum temperature for an adult is between 28 and 30 °C, with a preliminary study indicating an upper lethal temperature for the third instar of approximately 47 °C (Gressitt, 1953; Hawaii Invasive Species Council, 2014h; Moore, 2014b). The larvae favor high relative humidity, preferably 85–95% (Bedford, 1980). Although little information regarding the topography and elevation is available in the literature, Gressitt (1953) indicated that the pest is not typically reported at altitudes above 900 m. A map depicting the potential distribution of the coconut rhinoceros beetle was constructed for important palm hosts in the contiguous U.S. ([Figure 4-4](#)). The known distribution of the coconut rhinoceros beetle indicates

that its distribution is limited more by host than climate; therefore, climatic parameters were not included when preparing the map. Because no reliable host acreage data was available, data on the presence or absence of coconut and oil palm were collected at a county level using the Biota of North America Program (BONAP) database (Christie, 2014; Kartesz, 2013).

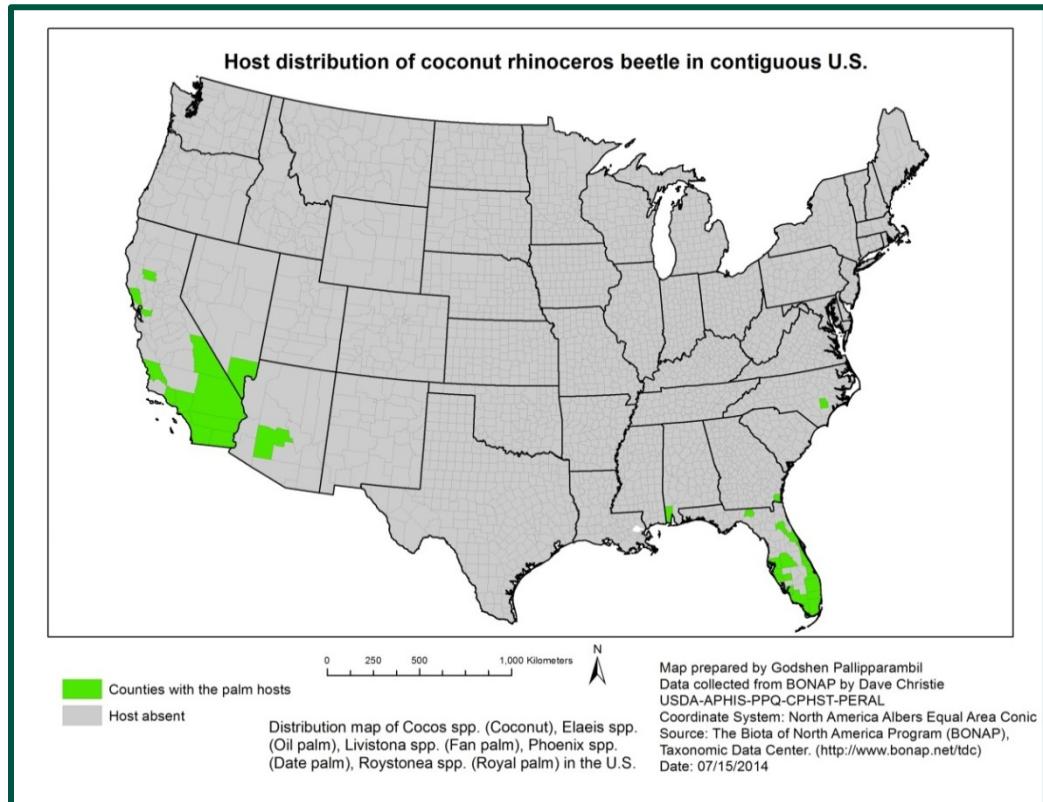


Figure 4-4 Potential U.S. distribution of *O. rhinoceros* based on host availability

Damage

Signs and Symptoms

Direct Damage

Activity Leading to Damage

Only adults cause damage, initially landing on an upper or middle frond and initiating an attack by squeezing between the axil and the stem (in a gap of 1.5–2.0 cm). The beetle creates entrance holes and tunnels toward the center of the palm to the undeveloped fronds and unopened inflorescences. After reaching the center, the beetle bores down to the terminal ‘cabbage,’ damaging the spears and spadix ([Figure 5-1A–C](#)). The beetle tunnels using its clypeus, fore tibiae and horn; the chiseling action of the mandibles and vertical movement of the head macerate the host tissue. The beetle ingests the sap exuding from the macerated tissue (Bedford, 1976b, 2013a; Gressitt, 1953; Vander Meer, 1987; Young, 1975). Occasionally, adults bore into the immature nuts of the palm; the mature green nuts are rarely attacked (Gressitt, 1953; Sullivan *et al.*, 2013). Although the attack on a palm is typically initiated at night, once inside, the insect feeds during all hours (Gressitt, 1953). [Table 5-1](#) provides the palm terminologies used in this section.

Table 5-1 Terminology and attributes of the coconut palm structures (Santos *et al.*, 1996; Young, 1975)

Term	Description
crown	‘crown’ of leaves atop palm; typically 25–40 leaves or fronds constitute crown
fronds	palm leaves; mature palms produce 12–16 fronds/year
leaflets	each frond divides further into leaflets
rachis	midrib of a frond
petiole	rachis base that attaches to tip of trunk
spear	undeveloped fronds; leaflets not exposed
inflorescence	single flower bunch located at axil of each leaf
spathe	sheath that envelops inflorescence
spadix	spathe + inflorescence

Visible Symptoms

As the damaged fronds unfold, the distinct ‘V’ or wedge-shaped cut characteristic of an *O. rhinoceros* attack becomes visible. This cut is caused by angular tunneling through the spadix that does not damage the rachis (Figure 5-1D–G). Damage to the rachis tip may cause the terminal portion of the frond to hang or break (Gressitt, 1953; Monty, 1978). During tunneling, fibrous tissue is typically pushed outward from the palm trunk and may be visible at the entrance hole (Giblin-Davis *et al.*, 2001). Entrance holes are approximately 2.5 cm in diameter, and the tunnels are 5–60 cm long. The entrance holes on the petioles and trunk may be visible from the ground depending upon the site and time of attack (Figure 5-1H–I) (Cherian and Anantanarayanan, 1939; Gressitt, 1953; Monty, 1978; Young, 1975).



Figure 5-1 Signs and symptoms of *O. rhinoceros* damage to coconut palms (photos G, H courtesy of Aubrey Moore, University of Guam; Arnold Hara, University of Hawaii [B, C, D, E, I]; images A, F by Geoffrey Bedford posted with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

Impact on the Host

Strong winds can break damaged rachis causing frond fall and reducing the area available for photosynthesis. A moderate attack may delay or reduce fruit production; a severe attack can cause all crown fronds to fall, gradually killing the palm (El-Shafie, 2014; Lever, 1969; Young, 1986). Dead standing palms eventually become a breeding substrate for the beetles (Figure 5-2). An attack on the spathe, inflorescence or immature nuts may cause early nut fall; a more severe attack directly impacts yield by destroying the inflorescence (Giblin-Davis *et al.*, 2001; Sullivan *et al.*, 2013). The palm is also killed if the beetle completely destroys the terminal growing point (Garlovsky *et al.*, 1971).



Figure 5-2 Coconut palms killed by *O. rhinoceros* in Fiji (image by Geoffrey Bedford, posted with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

The extent of palm damage varies with location, insect density, host structure and maturity. The impact of a beetle attack depends on the structure of the palm crown: The number of cuts may depend on the spacing between fronds; palm mortality and damage to the inflorescence may depend on the distance between the frond axils and growing tip. Spear growth and the positions of the developing inflorescence and beetle attack all contribute to palm damage (Young, 1975). Adults preferably attack mature coconut palms, although young palms are sometimes damaged (Gressitt, 1953). In Papua New Guinea, most damage occurred palms older than 3 years (Bedford, 1976b). Mature, healthy palms can tolerate an attack, but repeated attacks can cause palm death (Monty, 1978). Insect attacks are more severe in the growing apices of

1–3-year-old palms (Giblin-Davis *et al.*, 2001) leading to palm death (Young, 1986). The dead standing palms remaining after a beetle attack act as breeding sites, facilitating *O. rhinoceros* proliferation. Isolated palms or those situated at the edge of a plantation are often more exposed to beetle attack than other palms—possibly related to the insects' flight behavior. Adult beetles fly in a straight line and are sometimes unable to avoid obstacles (Monty, 1978).

Cumber (1957) notes that, on average, an adult beetle visits 3–4 palms during its lifetime. Adults may have approximately 7 flying events toward old or new hosts, but feeding duration on each host can vary (Vander Meer, 1987).

Favorable temperatures and rainfall also promote *O. rhinoceros* outbreaks (Jacob and Bhumannavar, 1991). If insect populations are low, beetle damage may not be fatal to the palm but can affect its aesthetic value. A healthy palm can produce approximately 1 frond/month, which, after unfolding, is resistant to beetle attack. In low insect densities, feeding may occur after long intervals allowing some palm fronds to evade attack (Gressitt, 1953).

The aforementioned signs and symptoms of *O. rhinoceros* damage to the coconut palm are similar to those in other less-studied palm hosts. In oil palms, the spears and unfolded fronds are attacked, and the crown may appear twisted (Dhileepan, 1992; Gressitt, 1953). Moslim *et al.* (1999) indicated that a severe infestation can kill young oil palms. Damage to the young palms can prolong the immature tree stage, causing significant economic loss during early crop production. If a beetle attack within the first 2 years of planting causes a 15% reduction in leaf area, crop losses can reach 25% (Darus and Basri, 2000; Ramle *et al.*, 1999). An attack on sugarcane is different: the beetle enters the stem at ground level and tunnels upward (Gressitt, 1953).

Indirect Damage

An *O. rhinoceros* attack may lead to secondary pest infestations and vice versa. A secondary infestation by palm weevils, *Rhynchophorus* spp., can prove far more dangerous than direct damage from *O. rhinoceros* (Bedford, 2013a; Catley, 1969; Giblin-Davis *et al.*, 2001; Manjeri *et al.*, 2014). Cherian and Anantanarayanan (1939) noted that trees attacked by the palm weevil are more attractive to the rhinoceros beetle. Sivakumar (2001) suggested that *O. rhinoceros* is attracted to the palms infested with *Rhynchophorus ferrugineus* Herbst once decay begins. Gressitt (1953) noticed that the rhinoceros beetles aggregate and attack the same palm when other healthy palms were available nearby.

Rainwater collecting in the excavated tunnels may also indirectly damage the palm causing stem rot (Cherian and Anantanarayanan, 1939; Gressitt, 1953).

Economic Impact

Impact on Yield

In both its endemic and introduced habitats, the coconut rhinoceros beetle primarily threatens coconut and oil palms (Cherian and Anantanarayanan, 1939; Chong *et al.*, 1991; Gressitt, 1953; Kamarudin and Mohd Basri, 1997). A beetle attack reduces the individual palm yield, and severe infestations can significantly damage plantations (Catley, 1969; Gressitt, 1953). A reduction in coconut yield is of particular concern for regions in which nuts are used for both consumption and the production of copra, oil and other byproducts (Bedford, 1980; Catley, 1969; Smith and Moore, 2008).

Trade

More than 85 countries cultivate coconut with Indonesia, the Philippines, India, Brazil and Sri Lanka as the top five. In 2010, global coconut production was approximately 62.5 million metric tons (Marikkar and Madurapperuma, 2011). The second-most preferred host, the oil palm, is cultivated by approximately 43 countries among which Malaysia and Indonesia are the two major producers, together constituting approximately 87% of global production (Punnuri and Singh, 2013). [Table 5-2](#) outlines the import and export of coconut and oil palm products in the U.S. [Adult Hosts](#) on page 4-8 provides comprehensive information regarding other hosts, and [Table 5-3](#) describes the impact of *O. rhinoceros* in some locations.

Table 5-2 Coconut and oil palm imports and exports in United States in 2011 (FAOSTAT, 2014)

Product	Import quantity (tons)	Import value (\$1,000)	Export quantity (tons)	Export value (\$1,000)
coconut	34,919	28,503	3,084	3,156
desiccated coconut	43,853	124,444	2,929	4,244
copra, oil	498,278	926,591	36,144	42,131
palm kernel oil	321,583	577,605	11,138	16,420
palm oil	1,087,626	1,281,840	94,906	107,491

The trade information in [Table 5-2](#) indicates that the U.S. is not a major producer of coconut and palm oil, but is the largest importer of desiccated coconut and coconut oil (FAOSTAT, 2014; USDA-FAS, 2014). The European and Mediterranean Plant Protection Organization (EPPO) lists *O. rhinoceros* as an A1 quarantine pest in the Caribbean, Central America, Brazil and the Pacific (PQR EPPO, 2013).

Cost of Control and Domestic Regulations

Removing mature infested palms and replanting is expensive. Pest management costs are also high due to the required phytosanitary measures, pheromone trapping, chemical control and release of entomopathogens. Adding to the costs, prophylactic phytosanitary measures and regular monitoring via traps are essential to limit the spread of the beetle even in regions currently devoid of the pest but with the potential for introduction (Bedford, 1980; Catley, 1969; Ramle *et al.*, 2013). An establishment of the pest triggers interstate regulations and international quarantine restrictions, further increasing the cost of an invasion (Campbell, 2011; Smith and Moore, 2008; USDA-APHIS, 2014b).

Socio-Cultural Impact and Aesthetics

In addition to their commercial value as cash crops, palms can be integral to a location's identity and culture; ornamental palms may add to the aesthetics of a business, increase property values and promote tourism. The destruction of palms by *O. rhinoceros* could negatively impact perceptions and damage lucrative businesses (Campbell, 2011; Smith and Moore, 2008; USDA-APHIS, 2014b).

Table 5-3 Damage from and economic impact of *O. rhinoceros*

Location	Economic impact	References
Guam	damage to businesses and tourism; expensive removal and replanting (current estimates for replanting mature palm US\$ 1,000 and replacing lost trees in Tumon US\$ 2.5 million); expense of quarantine restrictions; impact on small-scale household businesses dependent on coconut; potential high impact on culinary use and copra exports	Campbell (2011), Smith and Moore (2008)
India	10% yield loss due to spathe damage major pest of coconut and important but relatively minor pest of oil palm; in southern India, the percentage of damage in coconut palms ranged from 0.3–64%; in oil palms, the incidence is below 1.5–20%	Catley (1969) Dhileepan (1992)
	7.7–15.4% leaf damage in Kerala depending on the coconut cultivar	Muthiah and Bhaskaran (2000)
	crown damage in ~50% of palms in the Andaman Islands	Jacob and Bhumannavar (1991)
Malaysia	major pest of coconut and oil palms; ~25% oil palms attacked	Chong <i>et al.</i> (1991), Kamarudin and Wahid (1997)
	most severe damage to oil palms during second and third year of planting; almost no bunches if highly damaged	Oehlschlager (2005)
	~67% damage in 1–2-year-old tissue-cultured oil palms	Ahmad (2006)
Pacific Islands	major pest of coconut in Palau; 50% of palms killed within 10 years of introduction; no biological control 1968 annual estimate indicated approximately US\$ 1 million impact on South Pacific islands	Gressitt (1953) Catley (1969)

Environmental Impact

The environmental impacts of an *O. rhinoceros* introduction derive from direct damage by the beetle and control measures implemented to manage the invasion.

Direct Impact of the Beetle

Coconut rhinoceros beetles destroy mature coconut palms in agricultural, residential and native forest ecosystems (Cumber, 1957; Gressitt, 1953). In an agroecosystem, the beetle may variably impact palms and alter the age structures within a plantation (Campbell, 2011). In native forests, *O. rhinoceros* affects the diversity and distribution of flora by selectively targeting host species (Cumber, 1957; Gressitt, 1953; USDA-APHIS, 2014b). Decayed breeding substrates and hollowed-out palm trunks are habitats favored by several organisms; therefore, an infestation could influence faunal diversity (Gressitt, 1953; Hinckley, 1967). In some locations, coconut palms are planted along beaches to reduce erosion; because coastlines provide ready targets for beetle attacks, an infestation could increase soil erosion (Campbell, 2011; Gressitt, 1953). A U.S. introduction poses risks to approximately 400 endangered or threatened species (Pimentel *et al.*, 2001). Some protected plants are congeneric to the known hosts of *O. rhinoceros* and are therefore potential hosts. Refer to [Table 5-4](#) for a list of potential plant hosts with federal protected status (USDA-NRCS, 2014; USFWS, 2014).

Table 5-4 Threatened and endangered plant species that are potential hosts of adult coconut rhinoceros beetles (USDA-NRCS, 2014; USFWS, 2014)

Potential plant host	Federal protected status
<i>Agave eggersiana</i> Trel. (Eggers' century plant)	proposed endangered
<i>Agave × arizonica</i> Gentry & J.Z. Weber	endangered
<i>Pritchardia affinis</i> Becc. (Hawaii pritchardia)	endangered
<i>Pritchardia aylmer-robinsonii</i> H. St. John (Nihoa pritchardia)	endangered
<i>Pritchardia hardyi</i> Rock (Makaleha pritchardia)	endangered
<i>Pritchardia kaalae</i> Rock (Waianae Range pritchardia)	endangered
<i>Pritchardia munroi</i> Rock (Kamalo pritchardia)	endangered
<i>Pritchardia napaliensis</i> H. St. John (Nihoa pritchardia)	endangered
<i>Pritchardia remota</i> Becc. (Nihoa pritchardia)	endangered
<i>Pritchardia schattaueri</i> Hodel (lands-of-papa pritchardia)	endangered
<i>Pritchardia viscosa</i> Rock (stickybud pritchardia)	endangered

Impact of Control Measures

Phytosanitary measures including burning can pollute the environment; therefore, Malaysia rejects any strategy that involves burning (Ramle *et al.*, 2005b; Ramle *et al.*, 2011c). Several insecticides used for management and eradication pose environmental and health concerns; see [Chemical Control](#) on page 8-14.

Pathways

Natural Movement

Coconut palms grow along ocean shores in many locations. After infestation, some decaying palm logs may travel short distances through the sea (Gressitt, 1953; Lever, 1969). Adults can fly long distances under adverse conditions, but likely will not if breeding and feeding sites are available at the location of origin (see *Natural Dispersal* on page 4-11 for additional information).

Human-Assisted Spread

Cargo such as timber, sawdust and copra are suitable substrates for the larvae; ships carrying infested materials can introduce *O. rhinoceros* to new locations (Gressitt, 1953; Stride, 1977). However, port interceptions and previous reports indicate that the most likely method of introduction occurs through adults that hitchhike aboard ships and flights. Early coconut rhinoceros beetle invasions in the Pacific islands possibly occurred through sea and air traffic during WWII (Catley, 1969; Nishida and Evenhuis, 2000). The beetles are active fliers at night, and containers loaded after sunset are more likely to have hitchhiking adults than those loaded during the daytime. Regulatory personnel have found beetles in empty pallets on shipments from Guam to the mainland (CRB TWG, 2014). Moore (2007; 2014f) speculates that the introduction into Guam could have occurred through gravid females in shipping containers originating from Asia. Gressitt (1953) and Stride (1977) reviewed a previously used method to reduce introduction through shipping—the vessels were anchored at least 4 km from the shore, and shipboard infestations were detected using light traps after sunset with monitoring of adult flight activity until dawn. The port interception database revealed that *Oryctes* spp. were intercepted 14 times, of which 10 reports came from airports and 2 from seaports. Therefore, hitchhiking aboard airplanes appears more likely (PestID, 2014). Fewer interceptions involved *O. rhinoceros* specifically; Table 6-1 lists interceptions of live adults at U.S. ports of entry.

Table 6-1 Recorded interceptions of *O. rhinoceros* in the U.S. (PestID, 2014)

Interception location	Date	Origin	Pathway
Kahului, Maui, HI	January 2003	Indonesia	coconut, wood product, maritime, permit cargo
	January 2003	Indonesia	woodenware, maritime, general cargo
Detroit, MI	October 2003	China	airport
San Francisco, CA	September 2010	Malaysia	<i>Oncidium</i> sp., cut flower, airport, permit cargo
Chicago, IL	December 2011	Sri Lanka	baggage, airport
Toledo, OH	August 2012	Sri Lanka	dried <i>Musa textilis</i> Née, inland inspection, general cargo
Honolulu, HI	November 2013	Unknown	airport
Honolulu, HI	February 2014	Hawaii	pre-departure PPQ

Moore (2014f) noted that in Guam, soil bags high in organic content and stored outside (common in hardware stores) are frequently infested with *O. rhinoceros* larvae. Adults are occasionally reported in the beds of pickup trucks (Moore, 2014f).

On Oahu, Hawaii, an adult *O. rhinoceros* was detected at the international baggage claim area of the Honolulu airport in November 2013; however, no additional adults were reported nearby at the time, and the incident was considered an isolated event. In December 2013 the first adult was reported in Hawaii outside the ports and breeding sites, and multiple adult detections were subsequently made near the Joint Base Pearl Harbor-Hickam and the Honolulu International Airport, suggesting that the introduction may have occurred through air transport from either location (USDA-APHIS, 2014b). Using PCR-restriction fragment length polymorphism (RFLP), Moore and Marshall (2014) compared DNA samples from beetle populations in Hawaii to those in Diego Garcia, Fiji, Guam, Samoa and Papua New Guinea; results suggested that the infestation in Hawaii may have originated from Guam. [Table 6-1](#) lists suspected methods of *O. rhinoceros* introduction at various locations.

Survey

Survey Types

Plant regulatory officials will conduct detection, delimiting and monitoring surveys for *O. rhinoceros*. A *Detection Survey* will be conducted to ascertain the presence or absence of *O. rhinoceros* in an area in which it is not known to occur. After a new detection in the United States, or when detection in a new area is confirmed, a *Delimiting Survey* should be conducted to define the extent and geographic location of the insect. In addition, when a control procedure is applied, its effectiveness should be measured via a *Monitoring Survey*.

Table 7-1 Decision table for selecting survey type

If you:	Use this type of survey:
are not sure whether the pest is present at a location	<i>Detection Survey</i> as described on page 7-1. Collect specimens and consult with the authorities listed in <i>Appendix D</i> to confirm identification.
know that the pest is present and need to define its geographic location	<i>Delimiting Survey</i> as described on page 7-6. Collect specimens and consult with the authorities listed in <i>Appendix D</i> to confirm identification.
have applied control measures and need to study their effect on the insect population	<i>Monitoring Survey</i> on page 7-16. Collect specimens and consult with the authorities listed in <i>Appendix D</i> to confirm identification.

Detection Survey

Detection surveys determine if a pest is present in a defined area and can be broad in scope to assess the presence of a pest or multiple pests over large areas or restricted to determine whether a specific pest or pests are present in a focused area.

Although negative results from a detection survey may not confirm the absence of a pest at a location, the results can provide reasonable confidence regarding pest occurrence.

Procedure

APHIS and state cooperators conduct pest detection surveys through the [Cooperative Agriculture Pest Survey \(CAPS\)](#) program, which is a part of the pest detection line item within USDA–APHIS–PPQ–PDEP. The state CAPS committee meets and develops the survey list for each state.

If the CAPS program determines that the pest should be surveyed, use the following procedure to conduct a detection survey for *O. rhinoceros*:

1. Prior to surveying, consider the pest phenology to determine the time of survey; *Oryctes rhinoceros* surveys can be conducted year round
2. Determine the potential survey sites; focus the survey in locations where *O. rhinoceros* is more likely to occur including the following:
 - ◆ Geographical areas suitable for pest occurrence as described in [Potential Distribution](#) on page 4-16 and typically based on favorable environmental conditions and the presence of specific plant hosts as reported in states/counties
 - ◆ Within the potential distribution area, survey specific locations that have [Hosts](#) suitable for the pest species
 - ◆ Areas of previous detection using adult pheromone traps and by inspecting larval breeding sites near high-risk areas such as international airports; refer to the [Pathways](#) section for additional information
3. Establish sentinel sites/targeted surveys
 - ◆ Sentinel sites are regularly inspected locations along a surveyor's normal route, e.g., a coconut plantation at a specific location can serve as a sentinel site to regularly monitor for *O. rhinoceros*
 - ◆ Use GPS to record the sentinel site locations and draw a map of the immediate area that includes reference points to aid others in finding the area if necessary
 - ◆ Flag the sampled site
 - ◆ Once a sentinel site is established, the surveyor should re-inspect it on a regular basis (bimonthly or monthly) as permitted by their regular survey schedule
 - ◆ GIS can be used to map the sentinel site locations to promote even coverage, particularly in high-risk areas near international ports and preferred hosts

4. Examine feasibility and cost effectiveness
 - ◆ Survey coordinators should determine if detection surveys for *O. rhinoceros* could be bundled with other ongoing or new surveys based on target habitat, seasonality, priority and/or pathway
5. Determine the survey technique(s)
 - ◆ After determining the sites and design/bundling of the survey, conduct the survey using the [CAPS-approved survey techniques for *O. rhinoceros*](#). Refer to the [CAPS-Approved Survey Methodology for Negative Data Appendix M-1](#) for additional information
6. Procure survey supplies using the [IPHIS Survey Supply Ordering System](#)
7. Practice safety, sanitization and compliance during a survey
 - ◆ Prior to beginning a survey, determine whether any pesticides have been recently applied rendering the inspection of coconut palm crowns and palm residue unsafe by contacting the property owner or manager and look for posted signs indicating recent pesticide applications, particularly in commercial fields or nurseries
 - ◆ If pesticides have recently been applied, inspect larval and adult substrates after the re-entry period
 - ◆ Host contamination during an *O. rhinoceros* survey is not a major concern; unless the surveyors use beetle hooks to remove adults from within the palm axils, little interaction occurs between the host and the survey tools
 - ◆ Determine and comply with all quarantine requirements that may be effective in the survey area
8. Collect survey data
 - ◆ [Data entry forms](#) are available from the CAPS Website for specific pests
 - ◆ Because information regarding *O. rhinoceros* is unavailable at present, refer to [Data Collection](#) on page 7-12
9. Preliminarily identify the survey samples
 - ◆ Morphological characteristics that may aid in preliminary identification of *O. rhinoceros* are described in [Identification](#) on page 3-1

10. After a positive occurrence is suspected in the collected samples, submit the suspected *O. rhinoceros* specimen(s) to the proper authority to confirm the detection

- ◆ See [Sample Submission](#) on page E-1 and [Taxonomic Support for Surveys](#) on page D-1 for further information

11. Record data for each survey site

- ◆ Survey records and data recording formats should be consistent for standardizing the collected information
- ◆ If automated field collection services such as the Integrated Plant Health Information System (IPHIS) are used, ensure that all surveyors are trained in the technology prior to initiating the survey and use the appropriate IPHIS templates for *O. rhinoceros*
- ◆ To reduce the burden on field data collectors, enter any known contact or address information into the database and hand-held data recorders prior to initiating the survey
- ◆ After the survey is completed, all data should be entered into the designated state or national pest database; for example, *O. rhinoceros* detection survey information is available from the [Pest Tracker](#) database

For additional information, refer to the CAPS survey guidelines (CAPS, 2014).

Techniques for Detection

A detection survey investigates the presence of a pest within a broad or focused area of interest using the following techniques:

Inspect Potential Breeding Sites

Refer to [Eggs and Breeding Sites](#) on page 4-2 for substrates suitable for *O. rhinoceros* larval development. In addition to the larvae, these sites also harbor other stages of the beetle. Refer to [Identification](#) on page 3-1 for morphological characteristics. Collect larvae that occur in typical *O. rhinoceros* breeding locations to confirm their identity. Early instars of *O. rhinoceros* cannot be distinguished from early instars of other scarab larvae. Therefore, if only early instars are available at typical *O. rhinoceros* breeding locations, collect and rear the larvae until the third instar before confirming identification.

Visually inspect for Host damage

Characteristic V-shaped cuts in coconut fronds are the best early indicators of an attack by adult rhinoceros beetles. For more information, see [Damage](#) on page 5-1 and [Palm Damage](#) on page 7-17. If the damage is minor and the palms are tall, the attack signature on the host may not be easily detected (Gressitt, 1953).

Install Pheromone Traps

Ethyl (S)-4-methyloctanoate (E4-MO) is an aggregation pheromone produced by the male *O. rhinoceros* (Hallett *et al.*, 1995) and is widely used to trap adults of both sexes. For further information regarding the traps and their placement, refer to [Traps](#) on page 7-17 and [Pheromone Traps](#) on page 8-3. Although there is no scientific evidence available for suitable trap densities for detecting *O. rhinoceros*, endemic areas have historically used 1-2 traps/2 ha to monitor pest occurrence. Therefore, lower (< 1 trap/2 ha) trap densities may be sufficient for detection. Furthermore, trapping should be focused in high-risk locations such as international airports and cargo ports.

Based on the proximity to the high-risk locations and host numbers, recommended detection trap density may vary. Therefore, a range is provided below:

- ◆ May range from: 12 traps/km² (32 traps/mi²); distance between two traps = 280 m; area covered by one trap=20 acres. [This was calculated by doubling the distance between traps for when the density is 1 trap/2 ha]
- ◆ May range to: 3 traps/km² (8 traps/mi²); distance between two traps = 560 m; area covered by one trap=77 acres. [Above trapping distance doubled]

Reporting Pest Detection Data

The detection information may be entered in the [Integrated Plant Health Information System \(IPHIS\)](#) and/or the [National Agricultural Pest Information System \(NAPIS\)](#). To report data in IPHIS, first compile all data and summarize by county.

Delimiting Survey after Initial United States Detection

The objective of a delimitation survey is to determine the spatial extent of an exotic pest incursion following detection. If *O. rhinoceros* is detected in the US, surveys will be conducted to determine the occurrence of an infestation and its spread. After the initial detection, a Technical Working Group (TWG) is formed to prepare a delimitation survey plan to investigate the spread of *O. rhinoceros*. The TWG may consider the following information to recommend a delimitation survey plan for the introduced species.

Prior to Delimitation

If the sampling used for initial *O. rhinoceros* detection was sparse and non-intensive, a high-intensity broad detection survey should be conducted prior to establishing a more focused delimitation survey. This broad and intensive detection survey confirms that no *O. rhinoceros* is present outside the potential area of delimitation and allows for a more efficient utilization of the available survey resources. However, if this broad detection survey confirms the occurrence in the general area of first detection, the TWG should develop a delimitation survey plan to address the detection.

The trapping density in a high-intensity detection survey depends upon the available resources and logistics. Deployment should also consider the resources and the time required for regular sampling from the traps, servicing of the traps, sample processing, recording and analysis of the trap data.

Delimitation Area

The total delimitation area may depend on information from the *Trace-Back and Trace-Forward Investigations*, the nearby host distribution, *Pathways* including the extent of natural and artificial dispersal, agency resources and logistics.

Survey Techniques for Delimitation

The survey techniques described below are based on the literature and historic/ongoing *O. rhinoceros* eradication programs outside the continental US.

Visual Survey of Host Damage

Characteristic V-shaped cuts in coconut fronds are the best early indicators of adult rhinoceros beetles; detection of damage should immediately be followed by a search for feeding holes and breeding sites. For more information, see *Damage* on page 5-1 and *Palm Damage* on page 7-17. If the damage is minor

and the palms are tall, the attack signature on the host may not be easily detected (Gressitt, 1953). In addition to trained researchers, visual inspection can be crowd sourced with the aid of multimedia, pamphlet and online resources. For example, trifold pamphlets were issued in Hawaii with information regarding the identification, biology and damage of the coconut rhinoceros beetle (Hawaii Department of Agriculture, 2014j; Moore, 2012w, 2014t, 2014x; Smith and Moore, 2008). Information from citizen scientists may be considered as preliminary unverified reports requiring further examination for confirmation.

Visual Survey for Pest Stages

Refer to [Eggs and Breeding Sites](#) on page 4-2 for substrates suitable for *O. rhinoceros* larval development. In addition to the larvae, these sites also house pupae and young adults. Refer to [Identification](#) on page 3-1 for their morphological characteristics.

Trapping

Pheromone Traps: Ethyl (S)-4-methyloctanoate (E4-MO) produced by the male *O. rhinoceros* is an aggregation pheromone that attracts adults of both sexes (Hallett *et al.*, 1995) and is widely used as a pheromone trap to survey the pest. For the literature basis of the following trap information, refer to [Traps](#) on page 7-17 and [Pheromone Traps](#) on page 8-3. For updated trap research, refer to the [Technology Report](#) section of guaminsects.net.

- ◆ Trap design/type of trap: Several traps have been tested to capture adult *O. rhinoceros*. The most common traps are as follows:
 - ❖ Vaned bucket traps (standard CRB pheromone trap)
 - ❖ Vaned bucket traps with ultraviolet-light-emitting diodes (UV LEDs): Capture 3× more adults than vaned bucket traps
 - ❖ Pan traps (barrel + pan + cone + pheromone + light) with or without substrate: Capture 16× more adults than vaned bucket traps
 - ❖ Fishnet traps: Recently developed in Guam; most efficient; capture 26–29× more adults than vaned bucket traps (Moore *et al.*, 2014)
- ◆ Placement of the trap:
 - ❖ Vaned bucket traps: Previous research reports trap heights between 1 and 8 m, but most studies indicate 1.5–3 m as suitable
 - ❖ Pan traps: Traps should be placed on the ground in open areas away from *O. rhinoceros* host palms; inspect the traps and refill the organic substrate when required

- ❖ Fishnet traps: Fishnet or *Tekken* gill net traps have a mesh size of 2.54 cm (1 inch) and are made from 0.25-mm nylon monofilament. Traps are laid using the fishnet to cover fresh organic palm waste that is attractive to the beetle. Adults fly to the substrate for mating or breeding and are trapped and killed when the net falls into the gap near their prothorax. Traps can also be used to capture beetles emerging from potential breeding sites (Moore *et al.*, 2014).
- ◆ Replace the lure and dispenser after 6–10 weeks (6 weeks recommended); lures should be inspected every week and replaced when liquid inside is gone; lure longevity may depend on wind, sunlight exposure and rainfall; service traps as required based on local conditions

Other Trapping Techniques: Artificial traps using food substrates, light traps and the non-pheromone attractant ethyl chrysanthemumate (now superseded by E4-MO) are also utilized to detect the presence of adults. See [Non-Pheromone Traps](#) on page 8-2 for further information. Combination traps were tested as part of the coconut rhinoceros beetle eradication program in Guam and Hawaii (Moore, 2014m). Examples of such traps include different combinations of food, pheromone and light as described in [Combination Traps](#) on page 8-8.

Other Sampling Techniques

Acoustic Detection: The chewing, scraping, movement and tunneling activities of the larvae and adults in wood substrates produce distinct temporal and spectral acoustic patterns that can be detected using vibration sensors attached to the substrate, which allow the surveyor to detect the cryptic *O. rhinoceros* without obliterating or dissecting the suspected host (Mankin *et al.*, 2011; Mankin and Moore, 2010; Moore-Linn, 2009). Adult beetles stridulate by rubbing the elytra and abdominal tergite; these characteristic stridulations vary with age, sex, courtship, aggression and distress (Laartech, 2004; Mankin *et al.*, 2009; Mini and Prabhu, 1990). Bedford (2014) noted that acoustic detection may not be a useful technique for detection if the *O. rhinoceros* population is larger and widespread at a location.

Detector Dogs: During beetle eradication efforts in Guam, dogs were trained to detect the *O. rhinoceros* larvae. The dogs were equipped with GPS and tracked to monitor new survey sites. More than 350 new breeding sites were discovered using this method (Moore, 2012a; Quitugua, 2010).

Other palm species should also be inspected; for example, survey nearby royal palms for damage (Bedford, 2014). Inspections should encompass larger areas particularly where hosts are known to occur. Once *O. rhinoceros* has been

confirmed, surveys should be most intensive around the known positive detections, focusing on the survey spots described in the following section.

Survey Spots

After determining the total area and technique(s) for the delimitation survey, the specific survey sites should be determined within the delimitation area and may depend on the following:

- ◆ Favorable microhabitats based on pest phenology, environmental conditions and topography: Refer to *Eggs and Breeding Sites* on page 4-2 for substrates suitable for *O. rhinoceros* larval development. In addition to the larvae, these sites also harbor other stages of the beetle, but adults leave the breeding sites to find and feed on the palm hosts.
- ◆ Hosts: If *O. rhinoceros* is detected in the US, the TWG should consider the preferred hosts of the pest near the detection area, spatiotemporal distribution of these hosts and the host phenology suitable to the pest. *Oryctes rhinoceros* adults reportedly feed on approximately 51 plant species from 10 families. The coconut palm is the preferred host, followed by oil and date palms. For additional information, refer to *Adult Hosts* on page 4-8.
- ◆ Pathways: Port interceptions and previous reports indicate that introduction likely occurs through adults that hitchhike aboard ships and flights. For additional information, refer to *Pathways* on page 6-1.

Trapping Density and Deployment

Depending on the survey technique, the sampling points can be arranged on a grid. The center of the grid is the site of initial detection, or core of infestation. The delimitation survey may also include multiple buffer zones with outer zones having relatively lower trapping densities than inner zone(s); all buffer zones have lower trapping densities than the core infestation area. The trapping density in the core infestation area and the buffer zones will primarily depend upon the biology of the pest species, its dispersal capacity, availability of hosts, suitability of the host phenology at the trapping time and operational logistics.

Ethyl (S)-4-methyloctanoate (E4-MO) is an aggregation pheromone produced by the male *O. rhinoceros* (Hallett *et al.*, 1995) and is widely used to trap adults of both sexes. The description of *Pheromone Traps* on page 7-7 includes general survey information regarding trap design/type, pheromone lure efficiency and abiotic factors that may influence trap captures. The following information is specific to delimitation surveys:

Vaned Bucket Traps

The extent of delimitation survey is sometimes influenced by the available resources and other logistics. The distance between traps can be computed using either of the methods described in [Table 7-2](#).

Table 7-2 Methods for computing trapping distances for vaned bucket traps in a delimitation survey

Recommendations based on scientific literature		
core infestation area	trapping density distance between traps are covered by one trap	50 traps/km ² (130 traps/mi ²) ~140 m 5 acres ¹
buffer zones	trapping density distance between traps are covered by one trap	12 traps/km ² (32 traps/mi ²) ~280 m 20 acres
Historic/ongoing <i>O. rhinoceros</i> programs outside conterminous U.S.		
Hawaii	trapping density at core distance between traps are covered by one trap	25 traps/km ² (64 traps/mi ²) ~200 m 10 acres
Guam (near quarantined area)	trapping density distance between traps are covered by one trap	247 traps/km ² (640 traps/mi ²) ~64 m 1 acre
other areas of Guam (outside quarantined area)	trapping density distance between traps are covered by one trap	0.2 traps/km ² (0.5 traps/mi ²) ~2300 m 1340 acres

¹Based on the 1 trap/2 ha information that is extensively reported in the literature, but is below the core delimiting density reported from Guam and higher than the trap density utilized in Hawaii

The decision table found in [Table 7-3](#) can be used when establishing a delimitation survey for *O. rhinoceros*.

Table 7-3 Delimiting survey decision table for *O. rhinoceros*

If you detect:	In:	THEN take this action:	AND supplement with:
≥ 1 adult or immature	the detection survey area	initiate trapping at a density of 130 traps/mi ² in a 2-mi radius core area around the detection site AND at the lower density of 32 traps/mi ² for another 2-mi radius beyond the core area	visual survey of hosts and breeding sites 4 mi ² around the detection site(s).

After detection, determine the delimitation area and distribute traps as illustrated in [Figure 7-1](#). Each square represents 1 mi², and the values indicate the number of traps. The trap densities in [Figures 7-1](#) and [7-2](#) are 130 traps/mi² in the core area and 32 traps/mi² in the quarantined buffer zone. [Figure 7-2](#) illustrates delimitation after multiple detections. If the core area and buffer zone overlap, two trap densities are provided within a square for the respective zones. The variable density illustrates that the trap numbers will vary along the borders of the

delimited zones where each square may include both core and buffer zones. The number of traps in Figures 7-1 and 7-2 were calculated using ArcGIS based on the area of each zone in a square mile. However, during an actual introduction, the host density and topography of the trapping locations should also be considered.

Consult the TWG to revise the delimitation survey following a pest introduction. Overlay the host and topography data using mapping software such as ArcGIS. For example, if hosts are prevalent in only 50% of a square, then reduce the number of traps in that square mile by half. Similarly, only suitable topography should be considered for surveying with trap numbers revised accordingly.

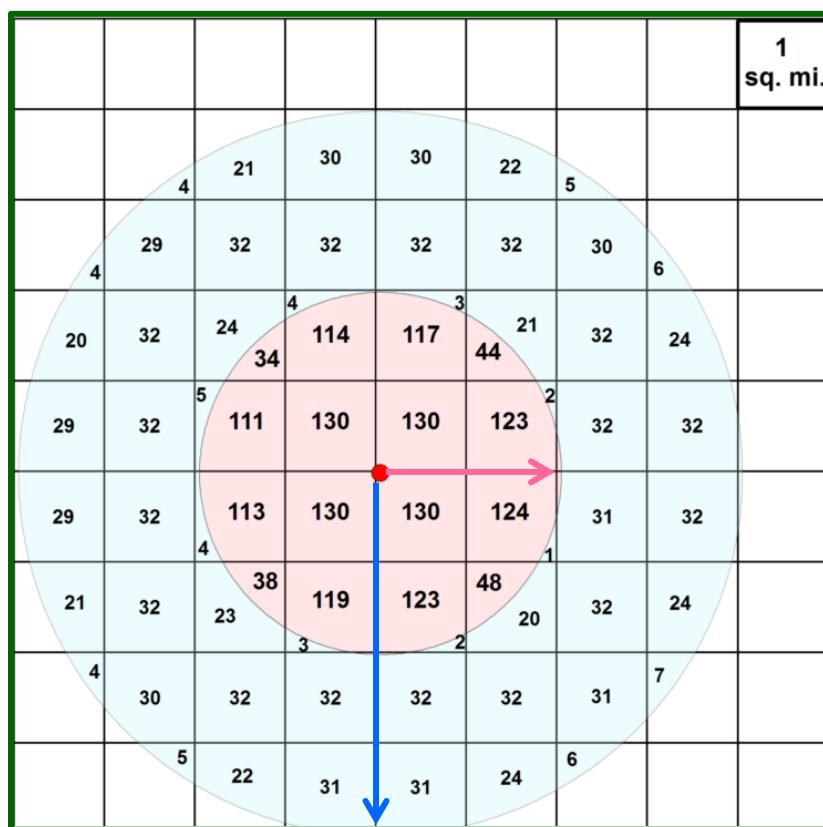


Figure 7-1 After first detection (red dot), traps should be distributed at high density in the core infestation zone (red circle) and at comparatively lower density in the buffer zone (blue circle). The core delimitation and buffer zones each have a 2 mi (red arrow) with a 4 mi (blue arrow) total radius around the positive detection.

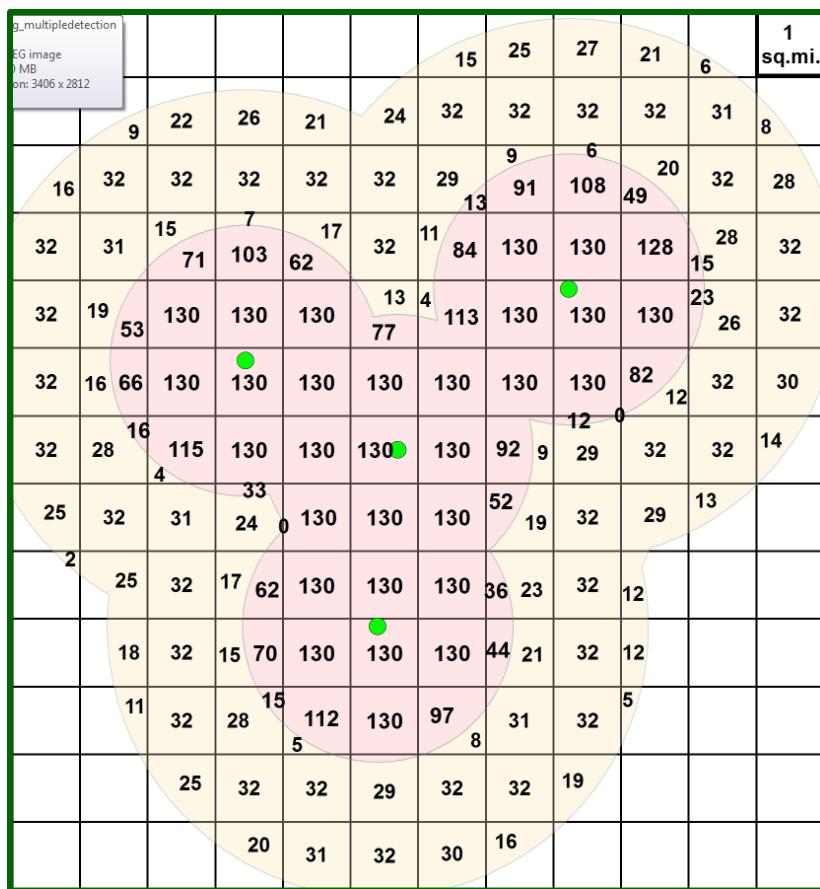


Figure 7-2 During the delimitation survey, additional positive detections (green spots) may occur, increasing the core and buffer delimitation survey areas

Safety, Sanitization and Compliance

Contact the property owner or manager and obtain permission before entering the property. Prior to the survey, determine whether recent pesticide applications might render the inspection of coconut palm crowns and palm residue unsafe. Contact the property owner and look for posted signs that may indicate recent pesticide applications. If pesticides have recently been applied, larval and adult substrates should be inspected after the re-entry period.

Host contamination during an *O. rhinoceros* survey is not a major concern: unless surveyors use beetle hooks to remove adults from within palm axils, little interaction occurs between the host and the survey tools. Determine and comply with all quarantine requirements in the survey area.

Data Collection

Flag the plant, tree or sampled location whenever possible, and draw a map of the immediate area, indicating reference points so that the areas can be found in the

future if necessary. **Do not** rely solely on the flagging or other markers to relocate a site as they may be removed. Record the GPS coordinates for each sampled area so that the area or plant may be re-sampled if necessary. Survey task forces should consist of an experienced survey specialist or entomologist familiar with *O. rhinoceros* and the symptoms of its damage.

Surveyors visiting sites to place holds or obtain samples should collect the following information:

- ◆ Date of collection or observations
- ◆ Collector's name
- ◆ Grower's field identification numbers
- ◆ Full name of business, institution, or agency
- ◆ Full mailing address including country
- ◆ Type of property (commercial nursery, hotel, natural field, residence)
- ◆ GPS coordinates of the host plant and property
- ◆ Host plant species and specific crop plant variety, if applicable
- ◆ Presence or absence of the pest
- ◆ Observations of signs and symptoms
- ◆ General conditions or any other relevant information

In the absence of inspection officials, take the following actions immediately if symptoms are noted:

1. Mark the location
2. Take samples of infested plant parts and flag the location within the field
3. Notify the state or PPQ inspector
4. Place the samples from the infested plant inside two resealable plastic bags
5. Label the sealed bags with the following information:
 - A. Date
 - B. Name of person responsible
 - C. Location of sample collection
6. Keep bagged samples cool or refrigerated until the inspector arrives
7. **Do not** freeze the samples

Identification

Morphological characteristics that may aid in the preliminary identification of *O. rhinoceros* are described in *Identification* on page 3-1. See *Appendix D* for taxonomic support information for the surveys.

After a positive occurrence is suspected in the collected samples, submit the pest specimen(s) to the proper authority to confirm the detection; see *Sample Submission* on page E-1.

Survey Records

Data should be recorded for each survey site. Survey records and data recording formats should be consistent for standardizing the collection of information. If automated field collection services such as the Integrated Plant Health Information System (IPHIS) are used, ensure that all surveyors are trained in the technology prior to initiating the survey. Use the appropriate IPHIS templates for *O. rhinoceros*. To reduce the burden on field data collectors, enter any known contact or address information into the database and hand-held data recorders prior to initiating the survey. After the survey is completed, all data should be entered into the designated state or national pest database.

Duration of Delimitation Survey

The delimitation survey is typically conducted until no target pest is detected for three generations of the pest species or until the pest species is de-regulated. The total lifespan of *O. rhinoceros* typically ranges from 4–10 months, allowing for more than 1 generation/year and therefore, delimitation survey may be discontinued if this insect is not detected for 12–30 months. However, eradication of an established *O. rhinoceros* population may not be feasible. Historically, the only report of a successful eradication is from the Niutatupapo Island, a small (6 mi²) island belonging to Tonga (Catley, 1969), by destruction of potential breeding substrates.

Historic and Ongoing Delimitation Programs

Program in Guam

The beetle was first detected in Tumon Bay in September 2007 (USDA-APHIS EPICA, 2007). After detection, a delimiting survey by the Guam Department of Agriculture and the University of Guam suggested that the infestation extended only to Tumon Bay and Fai Fai Beach. Therefore, an eradication zone of 1,360 acres was delimited; however, a larger quarantined area including 5,830 acres outside the eradication zone was designated to

consider potential spread. Delimiting traps were spread along Guam roadsides at the rate of 1 trap/1,340 acres, below the mass-trapping control rates of 1 trap/acre. (Guaminsects.net, 2007a; Smith and Moore, 2008). The quarantine area was later expanded to 28,362 acres (Campbell, 2011). In Guam, new trap designs are being investigated to increase the number of captures in pheromone lures. For further information regarding the traps and their designs, see *Pheromone Traps* on page 8-3.

Program in Hawaii

An adult was first detected on Oahu on 23 December 2013 near the Joint Base Pearl Harbor-Hickam; 2 weeks later, a severely infested mulch pile was identified nearby Hickam's Mamala Bay golf course. A few adults were subsequently discovered in adjacent traps, which led to the formation of an Incident Command System (ICS) involving the USDA-PPQ, the Hawaii Department of Agriculture, the University of Hawaii at Manoa and the Hawaii Department of Land and Natural Resources with the objective of preventing the spread of the rhinoceros beetle and coordinating eradication procedures. After discovery of the core-infestation area, a 3.2-km (2-mi) radius buffer zone was established for intensive monitoring. Although the method is similar to mass trapping, delimitation trapping allows for a reduced trap density. The desired rate is 64 traps/sq. mi. (~25 traps/km²), and at present, approximately 280 traps are deployed in and around the infested area; visual inspections were also conducted within the delimited zone (Hawaii Department of Agriculture, 2014h; Hawaii Invasive Species Council, 2014b; USDA-APHIS, 2014b). Although most reports occurred within the buffer zone, on 21 May 2014, a male adult was detected in a panel pheromone trap in Barbers Point outside the zone, extending the buffer zone to the west and increasing the delimited area by 23.3 km² (9 mi²) (Hawaii Department of Agriculture, 2014a). As part of the eradication effort, approximately 66,000 palms and 150 breeding sites had been surveyed as of 28 May 2014, and approximately 1,200 panel traps set throughout Oahu to monitor the incidence. The newly developed pheromone traps coupled with solar-powered UV LEDs are more effective than traditional pheromone traps and were deployed on poles or suspended from non-host branches (USDA-APHIS, 2014b) (see *Combination Traps* on page 8-8 for additional details). As of 28 May 2014, approximately 520 larvae, 16 pupae and 360 adults were discovered at the breeding sites and in traps (Hawaii Department of Agriculture, 2014a). Figure 7-3 provides a map of the reported pest locations and buffer zones as of the publication date. Updates are available from the Hawaii Department of Agriculture website (USDA, 2014).

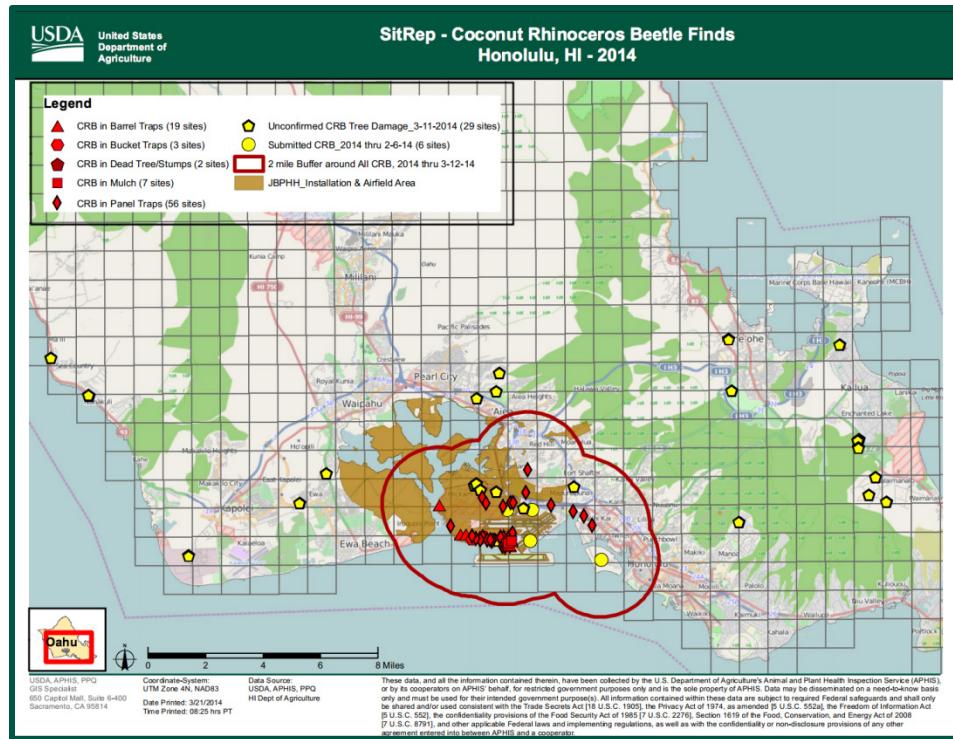


Figure 7-3 Hawaiian detection sites of *O. rhinoceros* adults and larvae; the red border denotes the quarantined buffer zone for delimiting surveys

Monitoring Survey

Conduct a monitoring survey if you have applied a control procedure and need to measure its effectiveness. If *O. rhinoceros* is detected in the United States, a TWG will be assembled to provide guidance on using a monitoring survey to measure the effectiveness of applied treatments. Refer to [Control Procedures](#) on page 8-1 for further information regarding control options.

Prior to Monitoring Survey

Prior to deploying pest eradication techniques and subsequent monitoring, the TWG consults with economists to develop an impact assessment for the introduced pest to determine if eradication is necessary or if a no-action plan is appropriate. Refer to [Damage](#) on page 5-1 for information useful for characterizing potential *O. rhinoceros* damage upon introduction to the U.S.

Procedure

All methods used in the detection and delimitation surveys can extend to monitoring; however, monitoring surveys focus on movement and seasonal dynamics. Because monitoring surveys investigate the density and spread of a

pest, larger samples are required than in a detection survey.

Typical monitoring trap densities may be as follows:

- ◆ 50 traps/km² (130 traps/mi²)
 - ❖ distance between two traps ≈ 140 m
 - ❖ area covered by one trap = 5 acres (most common in endemic areas)
- ◆ 100 traps/km² (260 traps/mi²)
 - ❖ distance between two traps ≈ 100 m
 - ❖ area covered by one trap = 2 acres

Literature-Based Examples

Two important monitoring techniques—visual inspection of plant damage and the placement of traps—are briefly discussed and examples provided in this section.

Traps

The aggregation pheromone produced by males can attract adults of both sexes and may prove helpful in studying *O. rhinoceros* population dynamics. In endemic locations, the typical density of pheromone traps is 1 trap/2 ha (Bedford, 2014). Kamarudin and Wahid (2004) monitored the dynamics of *O. rhinoceros* in and near a target oil palm plantation in Selangor, Malaysia. The survey used 49 pheromone traps spaced at 27 × 45 m to study the movement of *O. rhinoceros* in and out of the oil palm replanting areas; the study area was bordered by mature oil palm plantations. The traps were placed in 3 tiers: the first at the fringes, the second just inside the replanting area and the third—the ‘core’—further inside. The tiers were approximately equispaced. Trapping was initiated approximately 5 months after aging oil palms were felled, and all traps were placed at a height of 1.5 m. Lures were replaced every 6 weeks for monitoring over 2 years. The study noted that female adults immigrated into the replanting blocks much earlier and more frequently than males, indicating an active search for breeding sites. The core region was infested within 4–7 months of the logging of old palms (Norman and Mohd Basri, 2004). Although pheromone traps provide an index of the *O. rhinoceros* population in the vicinity, no studies have related the proportion of catches to the actual insect densities in the field. Therefore, the results from pheromone trap monitoring should be interpreted with caution (Bedford, 2013t, 2014).

Palm Damage

Zelazny and Alfiler (1987) noted that the number of catches using ethyl chrysanthemumate baits did not truly represent the *O. rhinoceros* population.

As alternatives, feeding damage reflects the numbers of beetles feeding at a site, and the position of damage on the palm fronds indicates the time at which the damage occurred. Based on the age of the palm, the number of fronds produced per year can be determined. For example, 1-year-old palms produce as few as 8.5 fronds/year, whereas mature palms produce approximately 16 fronds/year. For most of their lifetime, palms have 25–40 fronds in their crown (Young, 1975). Because the new fronds emerge every 3–4 weeks, the position of a frond in the crown of a coconut palm can aid in determining the age of each frond. Frond damage may vary depending on the type and time of attack; the damage severity and frequency can be used to estimate the population dynamics of the feeding adults on a plantation (Young, 1975; Zelazny and Alfiler, 1987). For more detailed sampling procedures, see the review by Bedford (2013a). [Table 7-4](#) provides a general outline of the survey techniques used at some locations. The techniques vary with the location, the availability of resources and the time of publication.

Table 7-4 Survey techniques for *O. rhinoceros*

Location	Summary	References
Guam	traps with pheromone and food substrates, detection dogs, preliminary studies using acoustics	Mankin and Moore (2010), Mankin <i>et al.</i> (2009), Moore (2012a)
Hawaii	solar-powered UV LED pheromone traps serviced every 1–2 weeks, crowd sourcing via social networks and citizen scientists, visual inspection of breeding sites and palm hosts	Hawaii Department of Agriculture (2014a, 2014e, 2014h, 2014j), Hawaii Invasive Species Council (2014a, 2014b, 2014h, 2014l), USDA-APHIS (2014a)
India	aggregation pheromone, weekly trap counts May–February on coconut plantations	Bhanu <i>et al.</i> (2012)
Thailand	November–May in aromatic coconut, examination of coconut fronds and breeding sites	Thai Agricultural Standard (2008)
Yemen	year-round monitoring using light traps at 1-km distances, weekly monitoring (trap catches high in March, gradually increasing to peaks again in June, then drastically decreasing after September)	Al-Habshi <i>et al.</i> (2006)

Trace-Back and Trace-Forward Investigations

Trace-back and trace-forward investigations aid in prioritizing delimiting survey activities after an initial detection. Trace-back investigations attempt to determine the source of the infestation. Trace-forward investigations attempt to define further potential dispersion through natural and artificial spread (commercial or private distribution of infested plant material). Once a positive detection is confirmed, efforts should be undertaken to determine the extent of the infestation or potentially infested areas to conduct further investigations.

After detection of *O. rhinoceros*-infested substrates or hosts, investigate the potential origin of infestation by determining nearby locations with high entry potential. Port interceptions and previous reports indicate that the most likely method of introduction occurs through adults that hitchhike aboard ships and aircraft.

Cooperation with Other Surveys

Other surveyors regularly sent to the field should be trained to recognize outbreaks that could be associated with *O. rhinoceros*.

Control Procedures

Overview of Emergency Programs

Plant Protection and Quarantine (PPQ) develops and makes control measures available to involved states. Environmental Protection Agency (EPA)-approved treatments will be recommended when available. If selected treatments are not labeled for use against the organism or in a particular environment, PPQ's FIFRA (Federal Insecticide, Fungicide and Rodenticide Act) coordinator is available to explore the appropriateness in developing an emergency exemption under section 18, or a state special local need under section 24(c) of FIFRA, as amended. The PPQ FIFRA coordinator and pesticide-use coordinators are also available upon request to work with the EPA to expedite approval of a product that may not be registered in the United States, or to obtain labeling for a new use. Refer to *Resources* on page B-1 for information on contacting the coordinator.

Treatment Options

Treatments may include the following:

- ◆ *Cultural Control and Sanitary Measures* on page 8-1
- ◆ *Chemical Control* on page 8-14
- ◆ *Biological Control* on page 8-19
- ◆ *Host Resistance* on page 8-40
- ◆ *Integrated Pest Management* on page 8-41

Cultural Control and Sanitary Measures

Trapping

Pest management programs for *O. rhinoceros* utilize traps to monitor the incidence and population dynamics of adults, auto-disseminate green muscardine fungus, capture adults for OrNV inoculation and release, mass-trap and kill the adults for a direct immediate impact on the population (Jackson *et al.*, 2010;

Ramle *et al.*, 2011a; Ramle *et al.*, 2005b; Young, 1986). The efficiency of the traps for *O. rhinoceros* control may depend on the lure/attractant, the trap design, spacing or distribution and the timing of their use.

Non-Pheromone Traps

Traps Using Food Substrates: In Vailele, Samoa, log traps were used during the 1950s to control the adult population (Cumber, 1957). The traps were constructed using 1-m-long decaying palm logs split longitudinally through the center. Approximately 12 split logs were arranged adjacent and parallel at an approximate distance of 25 m from the affected palm plantations. Adult beetles were attracted to these log traps after sunset and were collected and removed every 2 days. During rainy days, some adults remained at the palm crown. For this method to prove successful, other breeding sites should be eliminated from the target location, and trap activity should be closely monitored (Stride, 1977). The split-log trap design was not effective in Nigeria, but a modified design proved more attractive to adults (Hoyt, 1963). In Palau, Gressitt (1953) also noted that the split-log traps were not effective if compost pits or other attractive breeding sites were abundant at the trap location. In southern India, castor cake in combination with starch water provides growers with an indigenous technique to attract the adults to the bait. The fermented starch serves as the attractant, and the toxic alkaloids in the castor cake kill the beetles (Swapna and Ahamed, 2005). Previous studies reviewed the use of carbon bisulfide, rotten vegetables, compost pits, sawdust, fermented garbage water, green petiole leaves, coconut water, coconut debris, ragi water, yeast and acetic acid and bait traps involving other host plants (Gressitt, 1953; Rajamanickam *et al.*, 1992; Stride, 1977).

Light Traps: Adults are only moderately attracted to light traps even at high population densities (Gressitt, 1953). In Yemen, Al-Habshi *et al.* (2006) used light traps to monitor the population dynamics of *O. rhinoceros* adults in the field. However, further verification is required to confirm that the species in Yemen was indeed *O. rhinoceros* and not *O. elegans* or *O. agamemnon*, which are readily attracted to light and widely reported in the Arabian Peninsula (Bedford, 2014). In laboratory experiments in Hawaii, *O. rhinoceros* adults were attracted to ultraviolet light-emitting diodes (UV LEDs), suggesting importance in the light wavelength (Moore, 2013i).

Non-Pheromone Attractants: Prior to the discovery of the aggregation pheromone in *O. rhinoceros*, several synthetic attractants were evaluated for trapping adults, the most promising of which was ethyl chrysanthemumate (Barber *et al.*, 1971; Maddison *et al.*, 1973; Vander Meer *et al.*, 1979). This attractant was compatible with food substrates to trap breeding *O. rhinoceros*.

adults (Young, 1986; Zelazny and Alfiler, 1987). However, the popularity of this product waned after the commercial synthesis of a more effective aggregation pheromone, ethyl 4-methyloctanoate.

Pheromone Traps

After its commercial production, the male-secreted aggregation pheromone, ethyl 4-methyloctanoate, became the predominant attractant for trapping *O. rhinoceros* adults on coconut and oil palm plantations (Bedford, 2013a; Muñoz *et al.*, 2009; Raguissis *et al.*, 2007). In 1994, the compound was identified from *O. monoceros* and later described as a major pheromone in adult *O. rhinoceros* males (Allou *et al.*, 2006; Gries *et al.*, 1994; Hallett *et al.*, 1995; Morin *et al.*, 1996). Hallett *et al.* (1995) determined that ethyl 4-methyloctanoate was preferred 10 times more often by *O. rhinoceros* adults than the non-pheromone attractant ethyl chrysanthemumate. The racemic ethyl 4-methyloctanoate and the (S)-stereoisomer of the aggregation pheromone attracted the adult beetles equally; therefore, the chemical was characterized as ethyl (S)-4-methyloctanoate (Hallett *et al.*, 1995). Common abbreviations include ethyl 4-me-octanoate and E4-MO (Bedford, 2013a; El-Sayed, 2007).

Efficiency of the Pheromone Lure: The efficiency of a lure may depend on the dosage, longevity, trap design, trap placement, trap density, additives and abiotic factors (among other parameters). After identifying the aggregation pheromone, initial studies examined various rates of pheromone release in the lures. Although the capture rate increased with the release rate of the pheromone in a vane trap, the ratio of the impact to the release rate gradually plateaued above 6 mg/day (Hallett *et al.*, 1995). At present, commercial formulations are available with different dosages and release rates (BCRL, n.d.; ISCA, 2006; Sime Darby Plantation, n.d.). In many Southeast Asian countries, a pheromone lure sachet that contains 800 mg of active ingredient is used to trap the beetles (Loring, 2007). In a Thai study, Loring (2007) compared 2 commercial pheromone dispensers and noted that the lures were equally attractive. In Guam, initial studies indicated that the traps were not successful in mass capturing adults, but were a useful survey tool for detecting and monitoring the spread of the beetles (Moore, 2011). Subsequent studies have focused on increasing the trap efficiency. In a preliminary laboratory study, Moore (2013c) noted that the release rate of a lure changed over time and that the new lures exhibited the highest release rates during the first few hours, after which rates plummeted. This result indicates that a slow and steady release may provide lures with similar or higher efficiencies than standard lures. In a pilot assay, Moore (2013f) found no significant difference in the trap catch for the lures with standard (14.32 mg/day) and slow (1.41

mg/day) rates of pheromone release. Not all trap formulations are equally effective, Marshall (unpublished study, 2014) noted reliability in the lures from ChemTica.

The efficiency of a trap also depends on the lure longevity, which was relatively consistent across several studies. A survey in Malaysia noted that adults were caught in the traps as early as the second day and that the traps continued to attract for 6–9 weeks (Fee, 1997). The guidelines from a commonly used slow-release formulation recommends replacing the lures every 8–10 weeks (Sime Darby Plantation, n.d.). In Kerala, India, Sujatha *et al.* (2002) confirmed that the pheromone lures were effective for approximately 8 weeks and that the trap catches were highest during the second and fourth weeks. A study in Karnataka, India, tested the efficiency of 2 commercial pheromone lures and reported lure longevities reaching 10 and 14 weeks; however, the weekly breakdown of captures necessary to examine the efficiency of the traps over time was unavailable (Swamy and Puttaswamy, 2004). Some commercial formulations reportedly release pheromones more efficiently and last slightly longer, approximately 11 weeks (Loring, 2007), allowing the longevity of the traps to be extended.

The efficiency of the traps also depends upon environmental conditions. Based on preliminary studies conducted as part of the *O. rhinoceros* eradication program in Guam, Moore (2013c) noted that lure longevity may depend on wind, sunlight exposure and rainfall. A study at the oil palm plantations in southern India indicated that even a slight increase in the maximum daytime temperature above 33.5 °C impacted the efficiency of the pheromone lures and reduced the number of beetles trapped, possibly due to volatilization of the active pheromone ingredient. Variations in nighttime temperature had no impact on the lure captures. The lures lasted longer during the winter than the summer (Kalidas, 2004). Small landowners may be able to reduce costs by placing the lures in the trap only during the evening, thus eliminating excessive pheromone dissipation during the day (Desmier *et al.*, 2001). Some pheromone formulations may be relatively more efficient in regulating their release at high temperatures (Loring, 2007). In contrast, relative humidity was positively correlated with the number of beetles trapped (Kalidas, 2004), an observation likely due to the behavior of the beetles not the attractiveness of the pheromone. In general, flight activity increased during wet weather (Norman and Mohd Basri, 2004). Moore (2013c) indicated that rainwater may enter the lures via capillary action and interfere with trap efficiency.

Increasing the trap density may also enhance control: At low densities, traps may be ineffective, and at high densities they may attract additional pests to

the plantation increasing damage (Fee, 1997; Sujatha *et al.*, 2002). A study on the oil palm plantations in Malaysia indicated that pheromone traps set at the optimum density of 1 trap/2 ha captured 5.72 adults per week (Fee, 1997). In Tamil Nadu, India, traps are typically placed 1–2 traps/2 ha (TNAU, n.d.). A Malaysian study compared the impact of normal (1 trap/2 ha) and high (11 traps/ha) densities: At normal trapping density, the *O. rhinoceros* larval population declined to below 10 larvae/m² and stabilized. At high trapping density, the population declined below 10 larvae/m² for 16 months, after which no new individuals were detected (Norman *et al.*, 2007). A popular slow-release commercial pheromone formulation recommends 1 trap/2 ha (Sime Darby Plantation, n.d.). Loring (2007) indicated that these trap densities may be ineffective for high pest populations; thus, the number of traps should be based on the extent of infestation. Although trap density influences the number of insects trapped, other factors such as lure formulation and seasonal fluctuations also contribute. A 2000–2002 study testing the efficiency of a pheromone lure in Kerala, India revealed that the average trap counts were low at 3.3 adults per month, but could reach 18 per month, from March to June (Sujatha *et al.*, 2002). Swamy and Puttaswamy (2004) tested the efficiency of 2 commercial pheromone lures in southern India. Twelve traps at a density of 1 trap/2 ha captured 196 (lure 1) and 508 adults (lure 2) over 10–14 weeks. The aggregation pheromone traps captured adults in different sex ratios. Some traps caught more females than males (Jayanth *et al.*, 2009; Sujatha *et al.*, 2002), but the sex ratio was approximately 1:1 in most studies and male biased in some (Sakthivel *et al.*, 2008; Swamy and Puttaswamy, 2004). A 10-month multi-state study in southern India captured approximately 13,000 adults in pheromone traps, approximately 8,500 of which were females; many of these were gravid (Bhanu *et al.*, 2012; Jayanth *et al.*, 2009). Female flight activity increases when they actively search for breeding sites; therefore, the sex ratio bias at the time could have been behavioral and not due to differences in pheromone attractiveness (Norman and Mohd Basri, 2004).

Trap Design: After the adult senses the semiochemical, it flies toward the pheromone source, hits the barrier in the trap and drops into a 13–20-L bucket (Loring, 2007; Swamy and Puttaswamy, 2004). Hallett *et al.* (1995) compared 3 trap designs and determined that vane traps are more effective than pitfall or simple barrier traps; the cross vanes provide efficient barriers (Hallett, 1996; Hallett *et al.*, 1995). In a more recent review, Bedford (2013a) reported the use of 4 trap types to manage *O. rhinoceros* using pheromone lures—plastic bucket traps, parabolic traps, single- or double-vane barrier traps and a PVC tube trap. Several other trap designs are available according to the guidelines for commercial pheromone formulations and previous studies (BCRL, n.d.; ISCA, 2006; Jackson *et al.*, 2010; Sime Darby Plantation, n.d.).

For optimum capture rates, Fee (1997) suggested the use of pheromone lure sachets in black-painted vane traps suspended from wooden stands at a height of 3 m. The study indicated that the black-painted vane traps captured 1.5 times more adults than the non-painted vane traps. Kalidas (2004) later suggested that the vane bucket traps required improvement as they allow some beetles to escape, eventually leading to high infestations. Oehlschlager (2005) indicated that the beetles could not escape if the cross vanes extended inside to within 5 cm of the bucket base. Moore (2014f) confirmed that the beetles are unable to fly out of the vaned bucket pheromone traps, thus allowing trap installation without toxins or water at the base of the bucket. As part of the *O. rhinoceros* eradication program in Guam and Hawaii, researchers are testing modified and improved traps using ‘minibuckets’ and barrels covered with plastic tops, bird netting or chicken wire (Moore, 2013a, 2014a, 2014v, 2014w, 2014z; Moore and Quitugua, 2014a).

No consensus has been reached on trap height and placement. In Kerala, India, the pheromone lures were installed in vane bucket traps at 8 m to match the palm crown height (Sujatha *et al.*, 2002). In Karnataka, India, pheromone traps were attached to the palm trunk at a height of 2.5 m during a study to evaluate multiple commercial pheromone formulations (Swamy and Puttaswamy, 2004), whereas in Tamil Nadu, India, Sakthivel *et al.* (2008) secured the pheromone trap to a tree trunk at a height of 1 m using wire. In an area-wide study in southern India, the traps efficiently caught adult beetles at a height of 5 m; the sex ratio of the trapped adults was female biased (Jayanth *et al.*, 2009). Bhanu and Chandrasekharaiah (2013) described effective mass trapping at a rate of 2/ha in traps placed at chest height on the coconut palms. In Indonesia, Hallett *et al.* (1999) determined that the traps were efficient at either ground level or 2 m. In Malaysia, a height of 1.5–2 m was typical (Norman and Mohd Basri, 2000), but Oehlschlager (2005) reviewed the use of vane traps at canopy level. Although previous studies used coconut palms to secure the traps, non-host stands are preferred for trap placement to avoid attraction to the host when a beetle approaches the pheromone lure.

Previous studies are not comparable due to variations in experimental design, location and associated parameters; however, reasonable assumptions can be drawn based on *O. rhinoceros* flight activities at a location. In his recent review, Bedford (2013a) poses several questions for future research including whether males release more pheromone at breeding sites or at mating sites. Answering these questions may aid in streamlining trap placement and target-specific behavioral phases of the pest. *Oryctes rhinoceros* flight activity and movement patterns are now tracked through visual observation, infrared trail cameras and radio via miniature radio tags.

Implementation, Impact and Integration: Areas replanted with young oil palms may be more susceptible to pest infestations than those with mature palms. In Malaysia, the Palm Oil Board recommends the use of pheromone traps 6–12 months prior to replanting, *i.e.*, approximately 6 months after the old palms are cut down inside the block. The removal of aging oil palms and the zero-burning policy increase the availability of breeding substrates, thus the *O. rhinoceros* population. Therefore, trapping focuses on reducing the number of *O. rhinoceros* already existing inside a block while trapping at the borders of the replanting block focuses on reducing the number of beetles that may immigrate from adjacent mature palms. The pheromone traps are placed in 2–3 tiers encircling the replanting block—one at the immediate boundary of the replanting block and the others approximately 15 palms inside the block. The distance between the tiers and traps is equivalent to the required plant-to-plant distance within a row of 15 oil palms. The trap density is increased if the pest damage and populations are higher in the surrounding areas. Field studies in Malaysia indicated that the number of adults captured using pheromone traps correlates with a reduction in palm damage and that additional gravid females, possibly searching for breeding sites, were trapped at the borders (Norman and Mohd Basri, 2000, 2004). Placing traps at the border is only effective in blocks without infested breeding sites (Desmier *et al.*, 2001; Loring, 2007).

Pheromone traps can capture adults on both oil palm and coconut plantations (Jayanth *et al.*, 2009; Muthiah and Mohan, 2002; Sakthivel *et al.*, 2008). Oehlschlager (2005) noted that a trapping rate of 1 pheromone lure/2 ha reduced oil palm damage by more than 90% and suggested that trapping is less expensive and more effective than chemical control. In the Middle East, more than 50,000 ha are mass trapped annually (Wraight and Hajek, 2009). Traps are also critical components of integrated pest management programs. In West Malaysia, Fee (1997) noted that mass trapping via pheromone is only effective at low pest densities, but can prove beneficial at high densities when combined with biological control agents like OrNV or *M. anisopliae majus*. Just as multiple strategies are adopted to efficiently manage a pest, one strategy can target multiple pests. *Oryctes rhinoceros* and *R. ferrugineus* co-exist on many coconut plantations, necessitating management strategies with broader impact. In a field study, Hallett *et al.* (1999) demonstrated no loss in effectiveness when 2 lures were placed in the same trap to attract both insects. However, the flight activity of the 2 beetles may not coincide (Chakravarthy *et al.*, 2014). For example, in southern India, *R. ferrugineus* trapping is best from October to December, but *O. rhinoceros* is preferably trapped from September to February. The population dynamics and flight activity of the rhinoceros beetle can vary; ideally, the trapping time and duration should be based on the pest–host dynamics at a given location, which is likely unknown.

Moore (2014m) recently reported that the use of pheromone traps alone may not reduce insect population; on the contrary, damage continues to palms in trapped suggesting that the hosts may be more attractive than the pheromone lures. A release and re-capture study supports this assumption as none of the marked beetles were re-captured in pheromone traps at the release location. At present, the University of Guam in collaboration with the USDA-ARS is investigating new semiochemical candidates using gas chromatography-mass spectrometry (GC-MS) and electroantennograms. Previous studies have also analyzed the cost of pheromone trapping (Loring, 2007).

Combination Traps

Combination traps were tested as part of the coconut rhinoceros beetle eradication program in Guam and Hawaii (Moore, 2014m). Some commercial pheromone formulation guidelines have also mentioned the use of pheromones in combination with other attractants (BCRL, n.d.).

Food and Light: As part of the eradication program in Guam, Moore (2013a, 2013i) investigated the use of barrel traps. Large 208-L barrels filled with a breeding substrate and coupled with solar-powered UV LEDs attracted *O. rhinoceros* adults. Chicken wire covering the barrel allowed the adults to land and enter, but discouraged the insects from leaving. A preliminary study suggested that this food-based trap may be more effective than the pheromone traps. Furthermore, the addition of UV LEDs increased adult capture by 50% with UV LEDs proving more effective than white LEDs (Moore, 2014m).

Pheromone and Food: In Indonesia, Hallett *et al.* (1995) and Sudharto *et al.* (2001) demonstrated that the aggregation pheromone is more effective when combined with empty or rotting oil palm fruit bunches, indicating potential synergy between the pheromone and early fruit-bunch fermentation products. Bhanu and Chandrasekharaiyah (2013) combined the outer layers of tender coconut, detergent and water to attract and drown *O. rhinoceros* adults. High pheromone doses are expensive, but combining pheromones with readily available attractants may allow reduced dosages (Gunawardena, 2014).

Pheromone and Light: In a field trial, Moore (2013f, 2013i) evaluated the use of solar UV LEDs with slow-release pheromone lures (Figure 8-1). The addition of the light source enhanced the trap catches of *O. rhinoceros* 3-fold (Moore, 2013h). In 2014, these panel traps were deployed in Oahu, HI, to survey and trap the coconut rhinoceros beetle (Hawaii Department of Agriculture, 2014a). A ‘minibucket’ trap with a pheromone lure and UV LED is also being tested for efficacy (Moore, 2014m).



Figure 8-1 Traps and components used to monitor and control *O. rhinoceros* in Guam: (A) minibucket trap; (B) standard pheromone trap with UV LED; (C) slow-release pheromone and UV LED; (D) solar-powered and UV LED-fitted vane pheromone trap (photo courtesy of Aubrey Moore, University of Guam)

Newer Traps and Ongoing Research

Pan Traps: In Guam, a combination of food, pheromone and light is used to lure and trap beetles in large barrels (Hara, 2014; Moore, 2014m). The traps are prepared by filling the barrels with palm residue up to ~15 cm below the opening. The barrels are then covered with chicken wire. The 15-cm distance prevents the beetle from climbing out of the barrel, and the chicken wire prevents the flying adults from escaping (Moore and Quitugua, 2014b). The traps and some modifications are presented in Figure 8-2. Barrel traps (also known as pan traps) are the most efficient, capturing approximately 16-times more *O. rhinoceros* adults than nearby vanned bucket traps. The efficiency of a barrel + cone + pan + substrate + pheromone trap was equivalent to pan traps without a substrate (Moore *et al.*, 2014).



Figure 8-2 Barrel trap and components used in Guam: (A–C) barrel filled with palm residue; (D) UV LED placed above the trap; (E) a pan is sometimes used to collect the beetles; (F) pheromone lure (photos courtesy of Aubrey Moore, University of Guam [A–C]; Arnold Hara, University of Hawaii [D–F])

Tekken/Fishnet Traps: A fishnet or *Tekken* gill net trap has a 2.54 cm (1 inch) mesh and is made of 0.25-mm nylon monofilament. The trap is laid using fishnet to cover fresh organic palm waste, which attracts beetles. The adults that fly to the substrate for mating or breeding become trapped when the net falls into the gap near their prothorax killing them. These traps can also be used to capture beetles emerging from potential breeding sites. Furthermore, the fishnets can be tied around the base of palm petioles to capture adult beetles that are damaging the host. Pheromone lures are not required, and this trap is the cheapest and most effective found to date. A fishnet trap and captured adult are presented in [Figure 8-3](#) (Moore *et al.*, 2014).

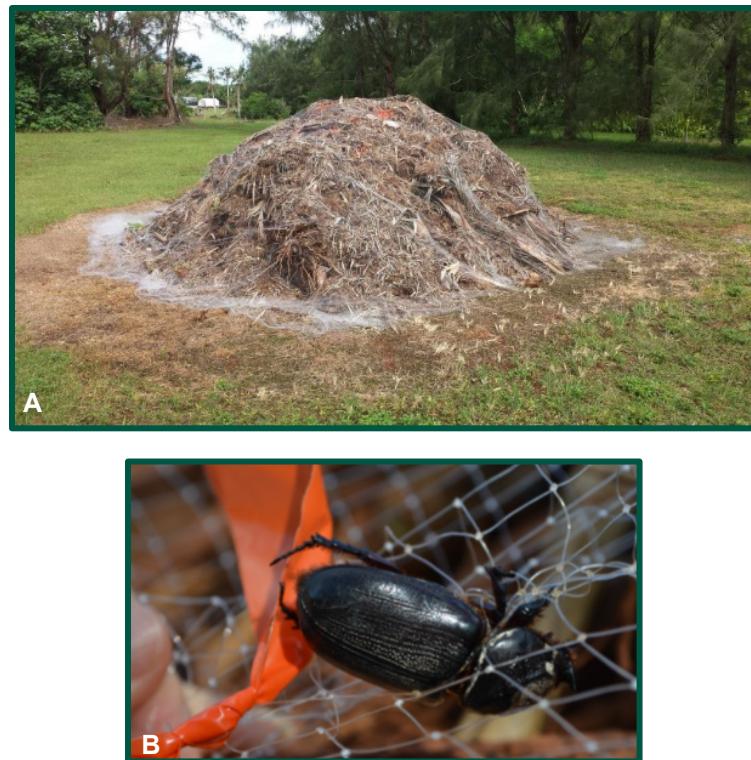


Figure 8-3 (A) New fishnet trap over palm residue in Guam; (B) beetle caught in fishnet trap (photos courtesy of Aubrey Moore, University of Guam)

Phytosanitary Measures

Dead standing palms, stumps, sawdust, compost and rotting organic matter all serve as substrates for *O. rhinoceros* larval development. For further information regarding suitable breeding sites, see *Biology* on page 4-1. Refer to *Table 8-1* for substrate management strategies adopted at various locations. Considering the larval development period, infested locations should be surveyed at least every 2 months to detect and eliminate breeding substrates (Gressitt, 1953).

Table 8-1 Management of substrates to prevent *O. rhinoceros* adults from breeding at specific sites

Substrate	Management	References
dead standing palms, other logs	used for construction; cut, split, stack, dry and burn; soak in water	Gressitt (1953), Philippine Coconut Authority (1998d), Stride (1977)
palm stumps	grow cover crops over stumps; treat with insecticides; treat with <i>M. anisopliae majus</i> (200-g suspension in 16 L water)	Philippine Coconut Authority (1998d, 2005), Stride (1977)
rotting organic matter, palm residue	treat with <i>M. anisopliae majus</i> or thinly scatter and mix with soil; construct incinerators for destroying infested material if needed; chip for use as feedstock for composting; fumigate with methyl bromide and bury immediately	Gressitt (1953), Moore (2012a), Muthiah and Mohan (2002), Philippine Coconut Authority (1998d), Stride (1977)
compost, farmyard manure	treat with <i>M. anisopliae majus</i> ; should not be placed inside palm plantations; prepare deep pits with small surface areas, cover or screen to prevent oviposition; turn at regular intervals and manually remove larvae	Catley (1969), Gressitt (1953), Muthiah and Mohan (2002), Philippine Coconut Authority (1998d), Stride (1977)
sugarcane bagasse	thinly scatter and mix with <i>M. anisopliae majus</i> ; feed to livestock; burn	Philippine Coconut Authority (1998d, 2005)
corn cobs	thinly scatter and mix with soil	Philippine Coconut Authority (1998d)
rice straw heaps	thinly scatter and inspect regularly	Philippine Coconut Authority (1998d)
garbage	burn or bury weekly	Stride (1977)
sawdust	thinly scatter and mix with <i>M. anisopliae majus</i> ; burn	Gressitt (1953), Philippine Coconut Authority (1998d), Stride (1977)

Burning is among the preferred methods for disposing of potential substrates, but can prove unsuitable depending upon environmental conditions, government policies or substrate conditions. For example, dry spells are brief in Samoa, preventing the processing of fresh palm residue prior to burning; thus, logs are soaked in water and sometimes cast into the open sea; however, the effectiveness of this method is unknown as the larvae can survive submerged in seawater for more than 48 hours (Catley, 1969; Gressitt, 1953; Nirula *et al.*, 1952). In Malaysia, a zero-burning policy established in the 1990s to sustainably manage oil palm plantations interferes with phytosanitary measures. Although environmentally desirable, palm residue may not be removed from the oil palm plantations even if infested (Ahmad, 2006; Darus and Basri, 2000). Burning is also unsuitable for heaps of partially composted materials. In Guam, alternative treatments such as the on-site application of insecticides or entomopathogens, burial and modified compost management are being examined. For the latter, the infested materials should be transported to a large-scale composting facility that produces high temperatures capable of killing the various *O. rhinoceros* stages, thus requiring the construction of large-scale infrastructure, which creates a limitation in some locations (Moore, 2012a). Grinding is considered an alternative

disposal method for heavily infested breeding substrates, but this too depends on the availability of equipment capable of processing large quantities of organic matter (Hawaii Invasive Species Council, 2014b). In Hawaii, the infested debris from the breeding sites was excavated and ground using ‘tub grinders,’ then returned to the excavation sites, placed on plastic sheeting and covered with a net to allow beetles to enter, but not escape. This method kills the different life stages during grinding and further provides a ‘substrate trap’ to lure and trap visiting beetles (Navy Region Hawaii, 2014). Ideally, the ground debris should be incinerated (USDA-APHIS, 2014b).

Previous studies recommended deep burial, which is often ineffective as the emerging beetles can tunnel through the soil (Gressitt, 1953). Alternatively, the palm residue could be fumigated prior to burial, but this method is expensive and environmentally unfriendly (Moore, 2012a). Other methods of sterilization such as solarization were examined, but *O. rhinoceros* easily survived the daily maximum temperatures; therefore, these methods were not pursued further (Moore, 2009, 2014b). The impact of steam sterilization requires further examination (Hawaii Invasive Species Council, 2014b). The coconut rhinoceros beetle larvae can withstand high temperatures, and preliminary studies suggest an LTe₅₀ for the third instars of approximately 47 °C (Moore, 2014b). Therefore, the lowest optimum temperature for killing the larvae via composting operations is under investigation in Hawaii by treating substrates, composting and re-treating at high temperatures of 55–77 °C (Hawaii Invasive Species Council, 2014h).

Cultivation practices, natural disasters, and an abundance of hosts can also interfere with phytosanitary measures. For example, underplanting is a replanting method utilized in oil palms in which young palms are planted under aging palms due to be felled in subsequent years; however, destruction of the infested mature palms prior to replanting is preferred. In some situations, natural disasters may interfere with the sanitation of plantations as they may leave an abundance of uprooted palm trees ([Figure 4-2I](#)) that serve as potential oviposition sites (Bedford, 2013a; Monty, 1978). The elimination of alternate beetle hosts may prove impossible. *Pandanus* spp. are economically important beetle hosts that are abundant in Palau for which scouting for infestation and selective elimination may provide a reasonable approach (Gressitt, 1953).

When removal is impossible, the substrates should be treated with insecticides or the entomopathogen, *M. anisopliae majus* (Chong *et al.*, 1991; Murphy, 2007; Stride, 1977). Currently, no insecticides effective against all stages of the insect are available, rendering insecticides unreliable for eradication (Hawaii Invasive Species Council, 2014b). Alternative methods were explored in some locations: Leguminous cover crops are grown over palm residues as barriers to obscure breeding sites from the adults (Vargo, 2000; Young, 1986). In the Philippines,

intercropping utilizes the space between the palms, thus reducing the accumulation of breeding substrates on unused land (Philippine Coconut Authority, 1998d). Replacing isolated older unproductive palms with younger trees in a coconut plantation can prevent selective *O. rhinoceros* infestations and potentially improve the overall health of the plantation (Vargo, 2000). Another ‘green’ technique involves chipping the entire mass of palm residue for use as feedstock for later composting operations. However, this method requires a large-scale composting infrastructure (Moore, 2012a). Educating and involving the community in phytosanitary measures often proves necessary (Moore, 2012a; Nair *et al.*, 1998; Peter and Kenmore, 2005; Secretariat of the Pacific Community, 2004; Young, 1986).

Mechanical Control

Adult beetles can be manually removed from palm crowns, axils and short borer holes using a rod or wire-hook assembly—a 50-cm-long iron rod or wire with a hook at its end (Cherian and Anantanarayanan, 1939; Muthiah and Mohan, 2002). This method is also known as ‘beetle winking,’ and is recommended at weekly intervals (Chong *et al.*, 1991). In southern India, the use of beetle hooks is recommended from June–September when the rhinoceros beetle adult population peaks (Nair *et al.*, 1998). Using sorting materials, all *O. rhinoceros* life stages can also be manually collected and removed from breeding sites; however, this method is laborious and may have only limited impact on the overall population (Muthiah and Mohan, 2002).

Chemical Control

Oryctes rhinoceros populations can be regulated by limiting the availability of larval breeding substrates. The substrates could be eliminated through phytosanitary measures, but not in all locations due to ‘zero-burn’ policies aimed at reducing air pollution. In some cases, treating the breeding sites with insecticides is preferred (Dhondt *et al.*, 1976; Howard, 2001). Bedford (2014) noted that chemicals may not be useful for eradication and may complement IPM strategies.

Juvenile Hormone (JH) Analogs

The JH analogs used as insect growth regulators (IGRs) can interfere with the action of naturally occurring JH, with the greatest impact occurring at metamorphosis. The JH analogs may reduce egg hatch, increase adult sterility or increase pupal mortality (Wilson, 2004).

Methoprene

Dhondt *et al.* (1976) tested 53 JH mimics and demonstrated that methoprene (isopropyl (2E, 4E)-11methoxy-3,7,11-trimethyl-2-4 dodecadienoate) exhibited the highest pupal mortality. In contrast, a recent lab study by Moore (2012a) indicated that methoprene was ineffective.

Pyriproxyfen

Moore (2012a) demonstrated that pyriproxyfen (2-[1-methyl-2-(4-phenoxyphenoxy) ethoxy] pyridine) prolongs the third instar stadium and prevents pupation. To reduce adult emergence in *O. rhinoceros*, Moore (2012a) recommends treatment of the palm stumps or other breeding sites with pyriproxyfen (10% AI) at a maximum rate of 56 mL per 190 L water using backpack sprayers.

Although JH mimics have low non-target toxicity and high target specificity, they lack an ability to rapidly impact an insect population (Wilson, 2004).

Organophosphates

Phorate

Phorate (O,O-diethyl S-[(ethylsulfanyl)methyl] phosphorodithioate) utilizes a cholinesterase inhibitor mode of action (Stenersen, 2004) and is commonly used against *O. rhinoceros* in Southeast Asia. Phorate granules (10G) can be placed in perforated sachets (5 g each, twice per 6 months) in the inner leaf whorls to reduce leaf damage by adult beetles (Rajamanickam *et al.*, 2002). Sometimes, phorate is used sequentially with naphthalene balls, neem seed kernel powder and carbofuran to maximize control and slow the development of insect resistance (Kumar and Ahmad, 2008; Muthiah and Bhaskaran, 2000; Rajamanickam *et al.*, 2002).

Trichlorfon

In Mauritius, trichlorfon (RS-dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate) was extensively applied (2% granules) to the youngest frond axils of coconut palms. Treatment of breeding sites was not recommended due to possible non-target impacts (Monty, 1978).

Chlorpyrifos

As part of the *O. rhinoceros* eradication program in Guam, chlorpyrifos (0,0 diethyl 0-(3,5,6 trichloro-2-pyridinyl) phosphorothioate) was sprayed into the bored holes and frond axils (23% AI, 0.5% solution) and applied to felled palm stumps (21.4% AI, 0.23% solution). The insecticide residues in the soil

and plants were expected to remain active for 2 years (Berringer, 2007). Subsequent studies suggested that this insecticide was ineffective for eradication and was therefore not pursued further (Moore, 2012a).

N-Methyl Carbamates

Carbaryl

Carbaryl (1-naphthyl N-methyl carbamate) is used to control *O. rhinoceros* in some locations (Pardede and Utomo, 1992). Rajamanickam *et al.* (2002) reviewed a 1:1 (or 1:2) mixture of carbaryl (5% D) and sand placed in the palm leaf axils (50 and 100 g per palm) as an effective prophylactic measure against beetle infestation. However, a further evaluation suggested less impact with the following ranking of effectiveness: phorate > naphthalene > carbofuran > carbaryl. As part of the coconut rhinoceros beetle eradication program in Guam, carbaryl (43% AI solution; 10G) was originally evaluated as an alternative to the no-action plan (Berringer, 2007). Preliminary studies suggested that this insecticide was not as effective and was therefore not pursued further (Moore, 2012a).

Carbofuran

Carbofuran is widely used against the coconut rhinoceros beetle in some south Asian countries (Darus and Basri, 2000; Kamarudin and Mohd Basri, 1997; Kumar and Ahmad, 2008; Muthiah and Bhaskaran, 2000; Padmasheela and Krishnan, 1996; Rajamanickam *et al.*, 2002; Stenersen, 2004). Although 12 products (US EPA PC code = 090601) are currently registered in the U.S., the EPA has now concluded that the risks associated with carbofuran are unacceptable at any level and has published a notice of intent to cancel the registration (EPA, 2011; Kegley *et al.*, 2010).

Synthetic Pyrethroids

Tefluthrin, bifenthrin, permethrin, fenpropathrin, cyhalothrin, cypermethrin, cyfluthrin, flucythrinate, fenvalerate, deltamethrin, fluvalinate, allethrin, lambda-cyhalothrin and tetramethrin were previously evaluated for use against *O. rhinoceros* (Darus and Basri, 2000; Faridah *et al.*, 2003). Darus and Basri (2000) reviewed two studies: in one, lambda-cyhalothrin was most effective against the pest on young oil palm plantations, and in the other, both lambda-cyhalothrin and cypermethrin impacted the beetle even at low concentrations. Most trials used cypermethrin as the pyrethroid of choice. The eradication program in Guam evaluated bifenthrin, which was later discounted as relatively less efficient (Berringer, 2007; Moore, 2012a).

Cypermethrin

Cypermethrin ($C_{22}H_{19}Cl_2 NO_3$) is widely used to control the coconut rhinoceros beetle. In nursery and field trials, cypermethrin significantly reduced the beetle population after 11 weeks and was effective even at low doses (Darus and Basri, 2000). In Malaysia, Oehlschlager (2005) reviewed the application of cypermethrin on each palm at biweekly intervals. Faridah *et al.* (2003) notes that severely impacted areas can be selectively and regularly sprayed with 0.05% cypermethrin at biweekly intervals. The cypermethrin residues accumulate in the digestive systems of *O. rhinoceros* larvae and concentrate in their body walls. Various cypermethrin 10 EC concentrations (0.125, 0.25 and 0.5%) were evaluated by Venkatrajappa (2001), with the most residue detected in the body wall from the 0.25% solution and the least from the 0.5% solution. In this study, toxicity was highest during the first 12 hours and declined to a minimum in 24 hours.

Cypermethrin (beta, 25.3% AI, EC) is used extensively in Guam as part of the *O. rhinoceros* eradication project (Figure 8-4) (Moore, 2012a) and may prove the ideal candidate for chemical treatment (Moore, 2014aa). Borer holes, frond axils, palm stumps and breeding sites including large compost piles were treated with cypermethrin (maximum 0.1% EC). The primary limitation of this pyrethroid is its rapid degradation in the environment, which necessitates frequent re-treatment of the breeding sites (Moore, 2012a).

Currently, 143 active products containing cypermethrin (US EPA PC code 109702 (beta); code 129064 (zeta)) are registered in the U.S. with formulations including an emulsifiable concentrate (EC), water-soluble powder (WSP), wettable powder (WP), suspension concentrate (SC), soluble concentrate (SL), granular (G), water-dispersible granule (WDG), dust (D), technical-grade, pressurized liquid, impregnated material, formulation intermediate and ready-to-use solution (Kegley *et al.*, 2010). Cypermethrin is registered for foliar application in food and feed crops, as a soil residual insecticide against structural pests and for direct application in animal husbandry (EPA, 2008; Kegley *et al.*, 2010). Like other synthetic pyrethroids, cypermethrin has low mammalian toxicity and a short environmental persistence (Faridah *et al.*, 2003).



Figure 8-4 Application of cypermethrin to young palm crowns (photo courtesy of Aubrey Moore, University of Guam)

Neonicotinoids

Although initially recommended for the integrated eradication program in Guam, imidacloprid—containing carbaryl, chlorpyrifos and bifenthrin—was subsequently determined to be ineffective (Berringer, 2007; Moore, 2008a, 2008b, 2012a).

Insect Repellants

Along with phorate and carbofuran, naphthalene balls were widely used in southern Asia to repel *O. rhinoceros* adults from coconut palms. In southern India, placing naphthalene balls (3 g each) at the base of the leaf sheath at the rate of 3 per palm over 45 days proved effective (Sadakathulla and Ramachandran, 1990). In Indonesia, naphthalene balls placed at the axils of palm fronds (5 balls per palm, 14 days) provided up to 97% control (Pardede and Utomo, 1992). Similarly in Malaysia, naphthalene balls in the frond axils yielded over 95% control, but were ineffective at high beetle densities (Darus and Basri, 2000). In Guam, the use of naphthalene balls did not have any impact on the insect population or infestation levels (Moore, 2014aa). Naphthalene has moderate acute toxicity and is possibly carcinogenic (EPA, 2003; Kegley *et al.*, 2010).

Fumigants

A methyl bromide fumigant was used to sterilize large volumes of *O. rhinoceros*-infested breeding substrates in Guam (Moore, 2012a). Although 164 products (US EPA PC codes 053201, 853201) are currently registered in the U.S., the EPA completed a phase-out of this fumigant in 2005, restricting its use to critical-use exemptions as defined by the Montreal Protocol (EPA, 2014; Kegley *et al.*, 2010).

Botanicals

Some indigenous techniques adopted by farmers in India were reportedly highly effective against larvae and adults. These treatments were predominantly used in combination or as follow-up. Neem oil, neem seed kernel powder (Padmasheela and Delvi, 2002; Rajamanickam *et al.*, 2002), dried cakes of *Hydnocarpus wightiana* Blume plants (Swapna and Ahamed, 2005) and powdered *Tephrosia purpurea* (L.) can be applied at leaf axils against the adults (Unnikrishnan Nair, 2012). Powdered *Clerodendron infortunatum* L. (Unnikrishnan Nair, 2012), *Chromolaena odorata* (L.) (Leena *et al.*, 2008), *Eupatorium odoratum* L. (Sreelatha and Geetha, 2008, 2010), *Adhatoda vasica* Nees, *Gliricidia maculata* (Humb., Bonpl. & Kunth) Steud. (Sreelatha *et al.*, 2011), *Ailanthus malabarica* DC. (Swapna and Ahamed, 2005) and *Mikania micrantha* Kunth (Zhong *et al.*, 2012) leaves and methanol extract of *Annona squamosa* L. leaves can be applied at the breeding sites against *O. rhinoceros* larvae (Sreelatha and Geetha, 2008, 2010).

Labeling

Although a proposed formulation may be approved for an effective eradication or control program, it may not be labeled, at the time of pest detection, for the specific use required. If a formulation is not labeled for the necessary use, one can request a federal crisis or quarantine exemption from the EPA under section 18 of FIFRA. For further information, refer to [Regulatory Procedures](#) on page 9-1. The prescribed formulation must be labeled for use on the site at which it is to be applied and must be registered for use in the state in which the eradication program is occurring. All applicable label directions must be followed, including requirements for personal protection equipment, maximum treatment rates, storage and disposal.

Biological Control

Biological and cultural control are useful for managing the coconut rhinoceros beetle. New biological control agents may not be plausible for an eradication program given the expected delays in approval, introduction and establishment of a biological control agent. Some applications of these agents are similar to synthetic insecticides with formulations that immediately impact the pest.

Predators and Parasitoids

A number of predators and parasitoids reportedly attack *O. rhinoceros*; however, only a few species are viable biological control agents ([Table 8-2](#)).

Table 8-2 Natural arthropod enemies introduced as biological control agents against *O. rhinoceros*

Predator	Host stage attacked	Country of origin	Notes	References
<i>Alaus speciosus</i> L. (Coleoptera: Elateridae)	all larval instars	Sri Lanka	established in Samoa	Catley (1969), Cumber (1957)
<i>Catascopus facialis</i> (Wiedemann) (Coleoptera: Carabidae)	larva		not established in Samoa	Gressitt (1953)
<i>Hypoaspis rhinocerotis</i> Oudemans (Acari)	egg			Khanjani <i>et al.</i> (2013)
<i>Lanelater fuscipes</i> L. (Coleoptera: Elateridae)	egg, all larval instars		established in Samoa; no impact in Mauritius	Catley (1969), Monty (1978)
<i>Neochryopussavagei</i> (Hope) (Coleoptera: Carabidae)	adult	Nigeria	not established in Fiji or New Guinea	Catley (1969), Bedford (1980)
<i>Pachylister chinensis</i> Quensel (Coleoptera: Histeridae)	first instar	Samoa	established in Palau	Gressitt (1953)
<i>Pheropsophus sobrinus</i> (Dejean) (Coleoptera: Carabidae)	larva	Kerala, India		Catley (1969)
<i>Pheropsophus</i> spp. (Coleoptera: Carabidae)		India	established, but no impact in Mauritius	Monty (1978), Bedford (1980)
<i>Platymeris laevicollis</i> Distant (Hemiptera: Reduviidae)	adult	Zanzibar, Malaysia, India, Sri Lanka	established in Samoa and Solomon Islands; not established in Mauritius, New Guinea, Tonga	Catley (1969), Lever (1969), Monty (1978), Bedford (1980)
<i>Scarites madagascariensis</i> Dejean (Coleoptera: Carabidae)	larva	Madagascar	not established in Mauritius	Surany (1960), Monty (1978)
Parasitoids				
<i>Elis romandi</i> de Saussure (Hymenoptera: Scoliidae)	larva	Madagascar		Lever (1969)
<i>Scolia oryctophaga</i> Coquillett (Hymenoptera: Scoliidae)	larva	Madagascar	not established in the Pacific	Gressitt (1953), Monty (1978), Bedford (1980)
<i>Scolia patricialis</i> Burmeister (Hymenoptera: Scoliidae)	larva	Singapore	not established in Palau	Gressitt (1953)
<i>Scolia procer</i> Illiger (Hymenoptera: Scoliidae)	larva	Malaysia	not established in Palau or Mauritius	Gressitt (1953), Monty (1978)
<i>Scolia ruficornis</i> F. (Hymenoptera: Scoliidae)	larva	Zanzibar	established in Samoa, not Palau or Diego Garcia	Gressitt (1953), Catley (1969), Lever (1969), Bedford (1980)

The scoliid wasps in Table 8-2 are larval ectoparasitoids of *O. rhinoceros* and have been studied extensively as biological control agents (Surany, 1960).

Scoliids require a cool period during the pupal stage and heavy rain during adult emergence; dry weather is unfavorable (Gressitt, 1953). *Scolia ruficornis* cannot enter hard wood and is restricted to decomposing and accessible friable breeding

substrates (Catley, 1969). Furthermore, the parasitoids are extremely susceptible to insecticides; therefore, chemical control is not recommended at the release sites (Lever, 1969).

Several species of ants, carabids, click beetles and histerid beetles feed on various life stages of *O. rhinoceros* (Cherian and Anantanarayanan, 1939; Gressitt, 1953). Some species of mites (*Hypoaspis* spp., *Macrocheles* sp., *Uropoda* sp.) are also recorded on *Oryctes* spp. (Cherian and Anantanarayanan, 1939; Jacob, 2000; Khanjani *et al.*, 2013). The impact of several of these predators remains unknown rendering them poor choices for biological control (Bedford, 1976b). In addition to the arthropods, several animals and birds feed on the coconut rhinoceros beetle, but these predators are not significant sources of mortality (Cherian and Anantanarayanan, 1939; Gressitt, 1953). Surany (1960) found that the control status of the coconut rhinoceros beetle in Southeast Asia cannot be attributed to its parasitoids and predators. Most of the predators and parasitoids introduced into the Pacific likely perished by the early 1970s (Young, 1986). Stiling (1993) notes that biological control campaigns in Samoa and Mauritius failed due to predation, climate and the habitat preferences of the released agents.

Nematodes

A few nematode species are associated with *O. rhinoceros*, but their host–parasite relationships are not well studied (Catley, 1969). *Oryctonema genitalis* n. gen., n. sp., is associated with the male aedeagus and female bursa copulatrix of *Oryctes* spp. (Bedford, 1980; Catley, 1969). Another nematode, *Rhabditis adenobia* sp. n., was reported from the colleterial glands of female *Oryctes* spp. (Bedford, 1980). *Thelastoma pterygonton* sp. n. was described from the larvae of *O. Monoceros* and was also found in *O. boas* (Poinar, 1973).

Green Muscardine Fungus

The green muscardine fungus, *Metarhizium majus* (J.R. Johnston) J.F. Bischoff, Rehner & Humber (= *Metarhizium anisopliae* var. *major*), occurs in the soil and attacks various *O. rhinoceros* stages (Bischoff *et al.*, 2009; Kepler and Rehner, 2013; Roskov *et al.*, 2014; Sathiamma *et al.*, 2001). Although the rates of natural infection are low, the fungus is an effective biological control agent against *O. rhinoceros* (Fernando *et al.*, 1995; Nirula, 1957; Tey and Ho, 1995). The fungus is more useful as a biopesticide component of integrated pest management at established locations than as a quarantine or eradication strategy (Bedford, 2014).

Identification of Infection

The fungus infects the *O. rhinoceros* larval, pupal and adult stages, but not eggs, and symptoms typically do not appear in early instars (Cherian and

Anantanarayanan, 1939; Nirula, 1957). In a larva, the initial symptoms of infection include sluggish movement, visible discoloration and dark brown lesions that appear throughout the body 3–7 days after inoculation ([Figure 8-5A](#)). The larva subsequently loses its appetite, sometimes moving out of the substrate onto the surface of the breeding site a few hours prior to death (George and Kurian, 1970; Nirula *et al.*, 1955). Post-mortem, the host body becomes opaque, white and soft, gradually shrinking and becoming mummified. The fungus fills the *O. rhinoceros* body cavity, and 2–3 days after death, breaks through the host integument as a white mycelial growth (George and Kurian, 1970; Nirula *et al.*, 1955). In another 3–5 days, the characteristic dense mass of green conidiospores appears and covers the cuticular surface of the rhinoceros beetle ([Figure 8-5B](#)) allowing spore dispersal (Nirula *et al.*, 1955; Philippine Coconut Authority, 1998a, 2005). Larvae rarely survive the infection to molt into adults. If a pre-pupal larva is infected, it typically dies in the cocoon before its final molt. Pupae are susceptible to infection; but generally do not exhibit symptoms prior to death; in some cases, a minor discoloration of the integument is noted. If the emerging adults are infected, they move out of the breeding substrate and exhibit a symptomatology similar to that of the larvae (Nirula *et al.*, 1955). Overall larval mortality occurs 1–3 weeks after the first sign of infection. The first instar dies in 1–2 weeks, and the second and third instars are typically dead in 2 weeks (Gopal and Gupta, 2001; Nirula *et al.*, 1955).

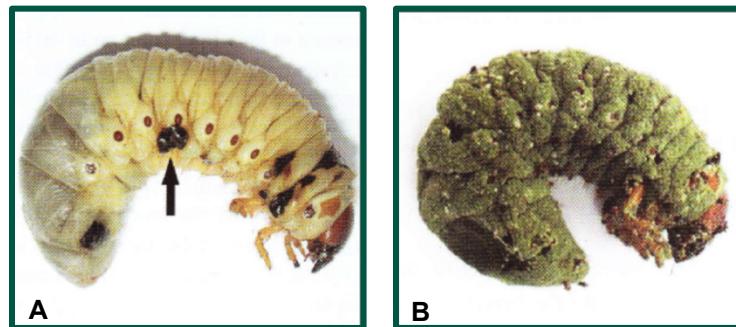


Figure 8-5 (A) Dark lesions characteristic of the initial stage of infection; (B) green conidiospores of *M. anisopliae majus* covering the larval cuticle of the *O. rhinoceros* (photo courtesy of Ramle Moslim of MPOB)

Inoculum Concentration

Concentrations of 10^5 – 10^6 spores/mL cause mycosis in 50% of the adults in 75–80 days (the lethal time, LT_{50}) for fungal isolates from *Oryctes* spp. (Ferron *et al.*, 1975). Although high inoculum concentrations improved control of *O. rhinoceros* larvae, Darwis (1990) demonstrated that a minimum of 10^6 conidia/kg of sawdust provided efficient control, killing 90% of the beetle larvae. However, this result may vary with substrate, environment,

larval distribution and other biotic and abiotic factors. In India, Gopal and Gupta (2001) recommended a concentration of 5×10^5 spores/mL for the initial establishment of the fungus and successful control of *O. rhinoceros*. In a laboratory study, Bhide and Patil (2005) recorded maximum larval mortality at multiple concentrations: 4×10^8 spores/kg cow dung led to 70% mortality in first instars after 10 days, 5×10^8 spores/kg led to 43% mortality in second instars after 18 days, and 5×10^8 spores/kg led to 53% mortality in third instars after 22 days.

Isolate Selection

The fungal isolates from *Oryctes* spp. are highly pathogenic to *O. rhinoceros*. In isolates from scarab species other than *Oryctes*, much higher (10–100-times) concentrations are required for a similar rate of larval mycosis (Ferron *et al.*, 1975). The pathogenicity of *M. anisopliae majus* isolates from 5 different *Oryctes* species and 2 other scarab species is presented in Figure 8-6. Isolates from *O. rhinoceros* larvae collected from multiple countries exhibited equally high virulence (Latch, 1976). Virulence decreases if the isolates are cultivated in artificial media for a prolonged duration, but can be recovered after infecting an *O. rhinoceros* host (Fargues and Robert, 1983). For example, Gallego and Aterrado (2003) demonstrated that an *in vivo* cultured inoculum of green muscardine fungus caused mycosis in 100% of the beetle larvae in 10 days, whereas an *in vitro* culture killed 96% of the larvae in 13 days. The reduced time to mycosis and higher mortality confirmed the increased virulence of fungal isolates cultured on the target host.

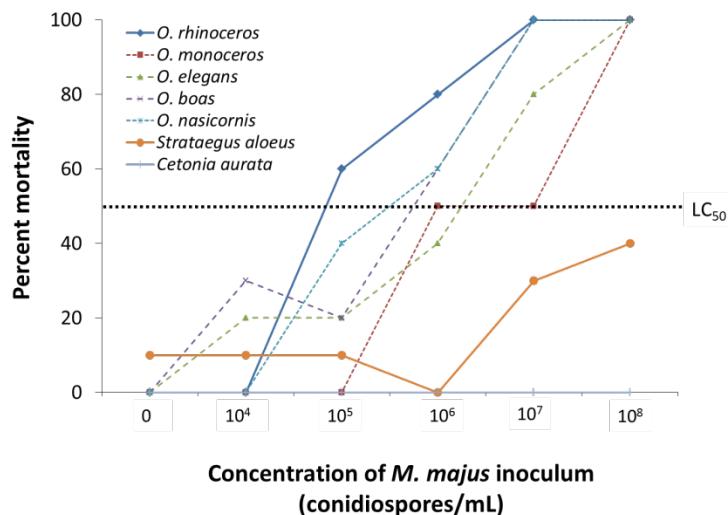


Figure 8-6 *O. rhinoceros* adult mortality at increasing concentrations of 5 *M. anisopliae majus* isolates (prepared using results from Ferron *et al.* (1975))

Persistence

Metarhizium majus is present at the breeding site throughout the year, but survival and the effectiveness of the inoculum may vary over time (Nirula *et al.*, 1955). In Malaysia, application of a pathogenic strain at breeding sites increased the rate of infection from 5–83% 4 months after inoculation; however, no long-term residual information was available (Tey and Ho, 1995). At the breeding sites in Tonga, Latch and Falloon (1976) demonstrated that some *M. anisopliae majus* isolates survived up to 2 years; however, infection reduced over time, dropping to 50–70% after a year. Persistence may vary; the fungus can remain from 1–3 years at a breeding site (Marschall, 1980). Cultural practices may increase or conserve pathogenic fungal inocula. Moslim *et al.* (2007) suggested that the cover crops often growing at breeding sites may interfere with the application of spores and delay the impact of fungal treatment on *O. rhinoceros* larvae; however, these crops may also provide conditions favorable for disease development. The establishment of the fungus depends heavily on high humidity conditions (Subaharan, 2004).

Conditions Favorable for Infection

Favorable temperature, relative humidity and overcast skies are important predisposing factors for green muscardine disease. The optimum temperature for *M. anisopliae majus* sporulation is approximately 28 °C (Ramle *et al.*, 2005a; Ramle *et al.*, 2006). In southern India, fungal infections were highest during the monsoon seasons under high rainfall and humidity (Nirula *et al.*, 1955). Independent of temperature, increased humidity appears to favor the spread of infection and insect mortality. In Samoa, the fungus, which occurs naturally in the soil, killed 25–30% of the larvae during wet years and 1–5% during dry years (Marschall, 1980). However, the performance of the fungus on *O. rhinoceros* depends on the interaction between temperature and humidity. The LTe₅₀ of the fungal conidia negatively correlates with the relative humidity (RH) ([Figure 8-7](#)). This relationship implies that a humid environment is detrimental to the viability of the spores if the temperature is extremely high. In contrast, at average temperatures, high humidity favors infection. For example, Nirula (1957) demonstrated that a RH above 70% at 23–31 °C was advantageous for disease development. Other studies indicated that spore germination was highest at 27–28 °C and relative humidities exceeding 95% (El Damir, 2006; Gopal and Gupta, 2001). Direct sunlight may also negatively affect the fructification of the fungus; cloudy weather facilitates disease development. In southern India, the disease developed most efficiently during overcast days with intermittent rainfall. A favorable period consisted of cloudy conditions on over 50% of the days with rainfall varying from 13–61 cm/month (Nirula, 1957).

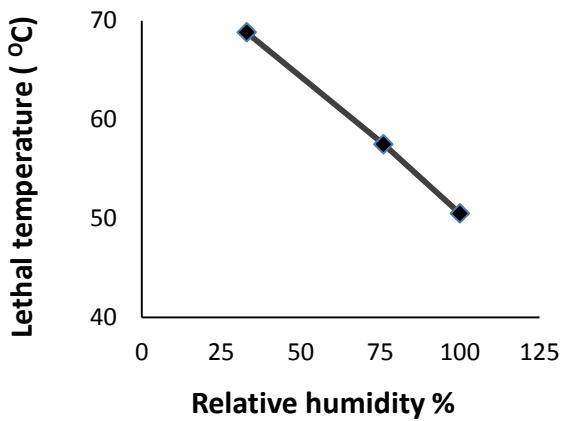


Figure 8-7 Relationship between the relative humidity and lethal temperatures of *M. anisopliae* conidia; graph prepared using results from a study by Zimmermann (1982)

Formulations and Impact

Solid Substrate with Fresh Spores: Sporulating solid substrates can be broadcast directly onto breeding sites. The spores can be mass cultured on rice (Zimmermann, 1993), oat grain (Latch and Falloon, 1976) or cooked corn (Tey and Ho, 1995) in autoclavable polypropylene bags. Moslim *et al.* (1999) demonstrated that a wet solid substrate is more effective and economical than a dry solid substrate. In India, an inexpensive supplementary nitrogen source such as fishmeal or urea is added to balance the C:N ratio and prevent pH variations that may deteriorate the substrate (Subaharan, 2004). Larval populations at treatment sites may be impacted as early as 3 months (Latch and Falloon, 1976). However, the viability of the spores on the substrates may decline over time, and the substrate quantity required to treat large areas may pose handling restrictions (Ramle *et al.*, 2013; Ramle *et al.*, 2006).

Spore Suspensions: A spore suspension can be prepared by harvesting spores from the liquid or solid substrate during mass production. A field study suggested that wet inocula, 10^8 – 10^{10} conidia in 10 L of water, were more effective and economical than dry inocula, 3–6 kg broadcast over a corn substrate. Three months after the application of dry or wet inocula, the treatment sites exhibited 37 or 51% mycosis, respectively, for all *O. rhinoceros* stages (Ramle *et al.*, 1999). In Malaysia, application of a fresh suspension, 1×10^{10} spores/mL, at the breeding site significantly reduced the number of larvae. The spore suspension can be delivered using hydraulic sprayers or trunk injection (Ramle *et al.*, 2013). In some cases, live larvae are dipped in the suspension and introduced into decomposing felled logs at a rate of 2 larvae/m of the log (Philippine Coconut Authority, 1998a, 2005).

Granules: An easy-to-apply granular formulation provides long-term control. Insect mortality was highest with a mixture of 925 g of kaolin and 400 g of

rice bran added to a 2-L suspension of *M. anisopliae majus* mycelia (Ramle *et al.*, 2009). Granules prepared from mycelia or spores were equally effective, killing 100% of the larvae in 18 days (Ramle *et al.*, 2008). Mycelia production was higher at pH 8 than at pH 5–7 (Ramle *et al.*, 2009).

Spore Dust: The Philippine Coconut Authority (1998a, 2005) suggests the use of spore dust on coconut stumps (1–2 tbsp/stump), piles of sawdust (1 tbsp/m²) and traps filled with breeding media (50 g/box). Powdered infected larvae can be applied directly to breeding sites (Gallego and Aterrado, 2003).

Other Formulations: In addition to conidiospores, dry mycelia and blastospores, whose pellets can be stored at low temperatures in vacuum-sealed plastic bags, are used against *O. rhinoceros* (Gopal and Gupta, 2001).

Delivery Techniques

Field application of fungal inoculum ideally occurs under the high humidity that typically coincides with rainfall (Subaharan, 2004). Optimum control is achieved when most larvae at the breeding site are molting. The *M. anisopliae majus* formulations can be delivered to the target breeding or feeding sites using several techniques as depicted in Figure 8-8. Moslim *et al.* (2013) describes fungus formulations on dry substrates or fresh spore solutions as effective for smaller breeding sites, but unsuitable for large-scale applications.

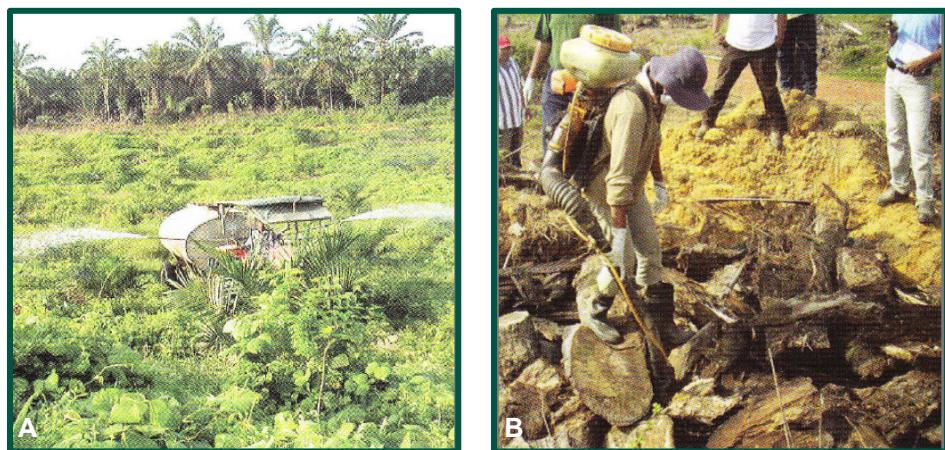


Figure 8-8 Delivery of *M. anisopliae majus*: (A) treatment of oil palm residues using a high-volume sprayer; (B) application of a spore solution at a breeding site (photo courtesy of Ramle Moslim of MPOB)

Mist blowers, power sprayers and high-volume sprayers are effective for field applications (Ramle *et al.*, 2013). For the first two, application rates as low as 0.5 g of spores in 3 L of water per m² of rotting palm heaps caused 100% larval mortality 3–5 weeks after treatment (Hamid *et al.*, 2005). For high-volume spray, 200–400 g of spores were mixed in 30–40 L of water at an

application rate of 0.75 L/m^2 on oil palm debris heaps with the first impact observed after 8 months when the insect population decreased 70% in the treated plots (Ramle *et al.*, 2013). Moslim *et al.* (2013) recommends using spore solutions in large flat *O. rhinoceros*-infested areas where the equipment and water resources necessary for high-volume sprays are typically available.

Adults may play an important role in spreading the disease as they are strong fliers and may transfer the fungal spores to other breeding or feeding sites. This ability of the adult can be exploited as a strategy for population control. For example, in Samoa infected live larvae and adult beetles smeared with a mixture of butter and spores were released at the target sites (Marschall, 1980). In Malaysia, adult beetles were collected using pheromone lures, dusted with *M. anisopliae majus* spores and manually released in a large target area to spread the spores (Ramle *et al.*, 2013). Spores can also be spread through auto dissemination traps. The adults are lured to traps using an aggregation pheromone mixed with a spore solution (2–4 g/L). The trap design allows most of the adults to escape and spread the fungus ([Figure 8-9](#)).

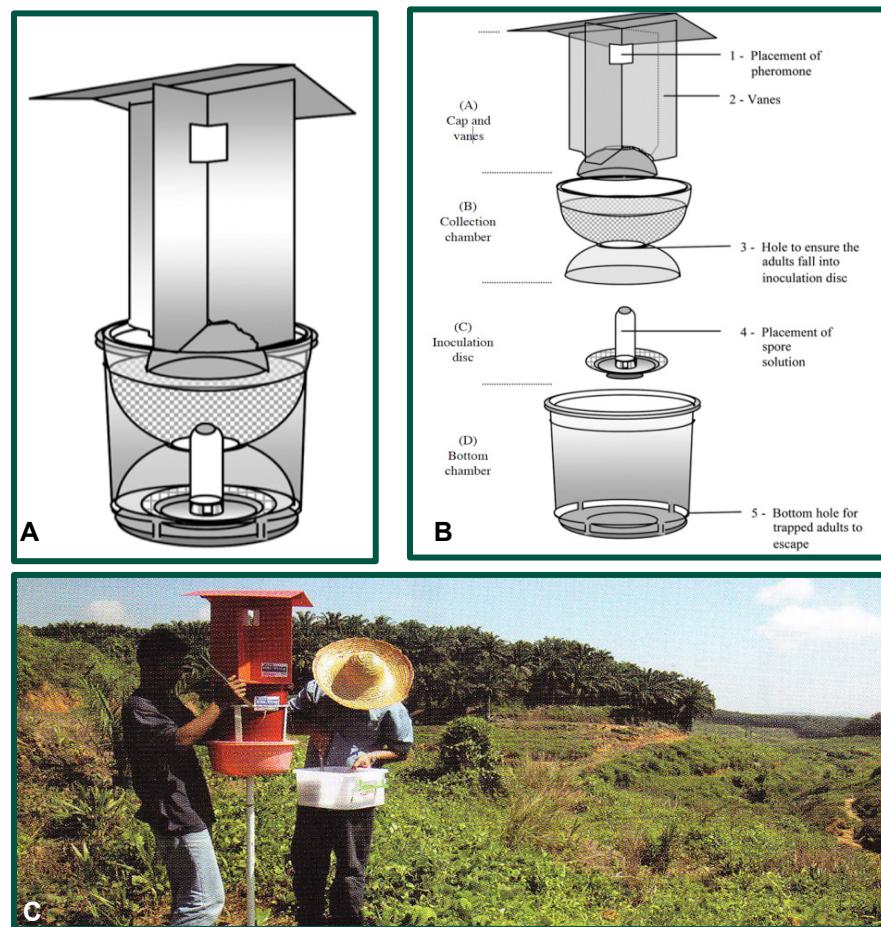


Figure 8-9 Trap for the auto dissemination of *M. anisopliae majus*; (A–B) trap design; (C) field use (photo courtesy of Ramle Moslim of MPOB)

A field study demonstrated that 85% of the trapped adults escaped and 67% were infected. The escaped adults infected and killed 92% of the larvae at the breeding sites. However, the spores spread through this method had low viability and did not significantly reduce the beetle population. Most of the escaped infected adults died within 15–30 days (Ramle *et al.*, 2011a). Given difficulties in application, auto dissemination traps remain preferable to sprays in undulating topographies. Moslim *et al.* (2013) recommends high trap densities to enhance spore concentration and distribution.

Moslim *et al.* (2013) reviewed the use of artificial breeding sites (1 trap/5 ha) to spread spores. An approximately 4-m-long, 2-m-wide and 1-m-deep trough was prepared as a breeding trap and was filled with palm trunk chips, which were allowed to decompose. To attract adults, a pheromone lure was placed adjacent to the trough. Different doses of *M. anisopliae majus* inocula were sprayed every 3 months for 1 year to infect the visiting adults and breeding larvae. Most adults were infected after contact and spread the spores to other breeding sites. This method produced 43% infection at the trap breeding sites, an improvement over the 32% achieved with the blanket spray of a spore solution (Ramle *et al.*, 2013). However, dispersion of the inoculum by the infected beetles is inefficient if the breeding sites are widely distributed (Young, 1986). In a similar study in Samoa and Tonga, trap breeding sites were sprayed with fungal spores to increase larval mortality and serve as an inoculum source to be spread by emerging or visiting adults (Marschall, 1980; Prior and Arura, 1985). A review by Moslim *et al.* (2013) indicated that the breeding traps were most effective on plantations with replanting programs.

Few studies have investigated the use of the green muscardine fungus against the adult feeding stage of rhinoceros beetles and other secondary pests. An *O. rhinoceros* attack can be followed by secondary and more serious infestations of *Rhynchophorus ferrugineus* Herbst and/or *Scapanes australis* (Boisduval). In Papua New Guinea, the green muscardine fungus was applied to the palm leaf axils using a pre-cooked rice medium (100 g/palm), which reduced *S. australis* damage by 32%, but had no significant impact on *R. ferrugineus* (Prior and Arura, 1985). Therefore, successful use of the biological control agent against secondary pests requires further investigation.

Safety

The fungus does not harm mammals and is considered of minimal risk to non-targets including humans (Gopal and Gupta, 2001; Zimmermann, 2007).

Metarhizium majus can also be used at the vermicomposting sites with no impact to non-target earthworms. The fungus selectively kills *O. rhinoceros* larvae at the tested concentrations (10^2 – 10^4 spores/g of substrate) (Gopal *et*

al., 2006). Moslim *et al.* (2007) demonstrated that spores applied in rotting palm residues have no significant impact on the oil palm pollinating weevil *Elaeidobius kamerunicus* Faust or the stag beetle *Aegus chelifer* MacLeay.

Advantages and Challenges to Implementation

The use of entomopathogenic fungi in integrated pest management (IPM) and insecticide resistance management (IRM) programs is increasing. The fungi aid IRM programs because fungal infections suppress enzyme activities in a pest, possibly increasing an insect's susceptibility to pesticides. Therefore, some IRM programs use entomopathogenic fungi in conjunction with sub-lethal insecticide doses (Ambethgar, 2009). However, some insecticides, like chlorpyrifos, inhibit the green muscardine fungus, and some carbamates are highly toxic to the fungus (Kao *et al.*, 2012). Future research should examine the compatibility of *M. anisopliae majus* with IRM and IPM programs.

Oryctes rhinoceros Nudivirus

After a long search for natural biocontrol agents for the rhinoceros beetle, a novel virus (originally designated as *Rhabdionvirus oryctes*, later *Oryctes* virus, *Oryctes rhinoceros* nudivirus (OrNV)) was isolated from diseased beetles in Malaysia and introduced into the affected Pacific Islands with a release on the Samoan islands in 1967 (Huger, 2005). Endemic to Malaysia, the Philippines, Indonesia and India (Mohan *et al.*, 1983; Sujatha and Rao, 2004; Zelazny, 1977a), OrNV has been effectively used worldwide in integrated management programs against the coconut rhinoceros beetle (Huger, 2005). The virus causes high levels of infections and epizootics in the beetle populations. At most release sites, OrNV infection causes larval mortality at breeding sites and reduced feeding and fecundity in adults, resulting in spectacular population declines. Typically, *O. rhinoceros* populations crash within 1–3 years of OrNV release with insect resurgence suppressed by additional applications (Jackson, 2009, 2014).

Isolates, Virulence and Host Resistance

The isolate from Malaysia was used globally in virus release programs from the 1960s to the 1980s with spectacular success in Pacific island and Indian Ocean states (Bedford, 1980; Bedford, 2013a). More recently, attention has been given to variations in virulence among strains from different locations. Zelazny (1979) carried out the initial studies, examining ten virus isolates obtained from Samoa and the Philippines and determined that the isolate, PB, from Leyte Island in the Philippines caused higher mortality than isolates from other locations. This study indicated differences in virulence among the isolates, but the number of virions in a 'standard dose' used to test the virulence was not accurately determined. Therefore, the reported differences

in virulence may be inconclusive. Furthermore, no genomic information was available for the virus at the time. In 1985, an OrNV genomic map was prepared using restriction enzymes on the virus isolate PV505 from Southern Luzon, the Philippines (Crawford *et al.*, 1985). This genomic information revealed significant genetic variations among OrNV isolates. In the Maldives, a field study evaluated 12 geographical isolates of the virus and determined that the X2B isolate from Bugsuk Island, Palawan, the Philippines, best reduced *O. rhinoceros* populations (Zelazny *et al.*, 1990). A Malaysian survey identified 4 distinct isolates—A, B, C and D—of varying virulence. Although type A, similar to PV505 from the Philippines, was naturally widespread at the location, type B (Ma07) was more virulent and effective against *O. rhinoceros* (Ramle *et al.*, 2005b). The virus types A, B and C, caused 27, 87 and 13% mortality, respectively, in third instars. The LT₅₀ was also significantly shorter for type B (34 days) than for other types (~100 days). In younger adults, the mortality and infection rates were significantly higher for type B, though type A had higher infection and mortality rates in mature adults (Ramle *et al.*, 2011c). Although the number of virions per dose was indeterminate, the study by Ramle *et al.* (2005b) attempted to use polymerase chain reaction (PCR) to quantify the viral DNA content in a dose to provide an index for determining virulence (Bedford, 2013a, 2014). Previous studies examined the probability of *O. rhinoceros* developing resistance to OrNV isolates, but no evidence suggests counter-resistance in the host insect (Crawford, 1988; Zelazny, 1979; Zelazny *et al.*, 1989). In Guam, Moore (2012a) tested the efficacy of 8 OrNV strains obtained from New Zealand on local *O. rhinoceros*. Preliminary assays determined that the strains did not affect the beetles, suggesting that the Guam biotype may be resistant to OrNV. Further studies are underway to examine the impact of OrNV on an imported susceptible population of the rhinoceros beetle (Moore, 2014m).

Detecting Infection

Pre- and post-release monitoring of OrNV levels in the *O. rhinoceros* population relies on accurate detection.

Visual: The virus readily infects *O. rhinoceros* larvae and adults without affecting the pre-pupa and pupa (Huger, 2005; Ramle *et al.*, 2011c). Adults exhibit higher percentages of infection than larvae (Ramle *et al.*, 2011c).

Infection of the larvae, initially deemed the ‘Malaya disease’ (Huger, 1969), causes the thoracic tergum to appear pearly, waxy and translucent; this obvious external symptom may be due to the cessation of feeding and absence of food in the midgut (Huger, 1966; Mohan *et al.*, 1985). The translucency, in direct contrast with the clear, dark midgut of healthy larvae, typically appears

5–8 days after the virus enters the larva (Mohan *et al.*, 1985). As the infection progresses, the abdominal fat, as observed through the integument, appears to disintegrate. The body becomes more turgid with an apparent increase in hemolymph that may lead to rectal prolapse (Huger, 2005). Infected larvae develop diarrhea, become lethargic, discontinue feeding and eventually move to the breeding substrate surface (Huger, 1966; Lacey, 2012). Significant reductions in food consumption, growth rate, digestibility and food conversion efficiency occur after infection (Paulose and Abraham, 1997). The virus typically kills the larvae in 1–4 weeks (Huger, 2005; Zelazny, 1972). During the final stages of infection, the layer beneath the abdominal integument develops chalky-white mottled accumulations. Post-mortem, larvae become flaccid, then shrink and mummify. Initially, the cadaver appears brownish, later turning bluish-black (Huger, 1966; Mohan *et al.*, 1985). Zelazny (1972) reported that 94% of all larvae die within 5 weeks of ingesting the virus, with total mortality occurring in 8 weeks; however, the duration may vary with the dose. Because the number of virions cannot be accurately determined, the longevity of infected larvae may not be useful (Bedford, 2013a, 2014).

Zelazny (1973e) suggests that the OrNV infection more significantly impacts *O. rhinoceros* adults than larvae. Although symptoms are not explicitly visible in adults, OrNV infection modifies their behavior and biology. Viral infection leads to feeding cessation within 1 week, decreased flight activity and reduced longevity (Zelazny, 1973a; Zelazny, 1977c). The infected adults die within 4–5 weeks (Zelazny and Alfiler, 1991). In males, decreased mating activity was also reported after infection (Zelazny, 1977c). The infection rate is typically higher in females and leads to reduced fecundity; thus, females in advanced stages of infection made significantly fewer visits to the breeding sites for oviposition than healthy females (Zelazny, 1973a, 1973e; Zelazny and Alfiler, 1991). A few cases of wing malformations were reported after a virus release in Mauritius (Monty, 1974; Zelazny, 1973a), although these malformations may be associated with damage to the pupal chambers (Zelazny, 1976).

Laboratory: Various techniques have been used to identify OrNV infection. The structure of the virus can be examined through electron microscopy (Huger, 1966; Jackson *et al.*, 2010; Mohan *et al.*, 1983; Payne, 1974). Gut symptoms can be examined via light microscopy (Gorick, 1980; Ramlah Ali *et al.*, 2001), inspection of adult excreta (Monsarrat and Veyrunes, 1976), dot-blot assay (Crawford, 1988), enzyme-linked immunosorbent assay (ELISA) (Longworth and Carey, 1980; Mohan and Gopinathan, 1989), immuno-osmophoresis (Mohan *et al.*, 1983; Mohan and Pillai, 1983), immuno-fluorescence (Croizer and Monsarrat, 1974), host mortality bioassays (Jackson *et al.*, 2010), DNA restriction endonuclease activity (Eberle *et al.*, 2012;

Ramle *et al.*, 2011c), solid-phase radioimmunoassay (Crawford *et al.*, 1978), direct antigen coating-indirect ELISA with dot-immunobinding assay (Rajamannar and Indiravathi, 2000) and PCR (Eberle *et al.*, 2012; Jackson *et al.*, 2010; Ramlah Ali *et al.*, 2001; Ramle *et al.*, 2010; Ramle *et al.*, 2001). Ramle *et al.* (2010) optimized the PCR reaction to yield the single 945 bp band using a primer pair developed by Richards *et al.* (1999):

OrV515a = 5'-ATTACGTCGTAGAGGCAATC
OrV515b = 5'-CATGATCGATTCGTCTATGG

During pre and post-release OrNV monitoring, cross-contamination can occur in beetles collected in traps, inflating the infection rates (Ramle *et al.*, 2005b). To reduce cross-contamination, adults collected in traps could be processed immediately, separated or stored under conditions that prevent disease spread. Early stages of viral infection are detectable via PCR and ELISA (Bedford, 2013a; Ramle *et al.*, 2011c).

Dissemination of the Virus

The success of the virus for biological control depends on auto-dissemination by adult beetles. The gut lumen of the infected adults fills with sloughed-off midgut epithelial cells with proliferating virus particles in their nuclei. The infection causes diarrhea in adults, potentially spreading the virus at the mating, feeding and breeding sites (Huger, 1966). Infected adults typically produce 0.3 mg of virus in their excrement daily (Monserrat and Veyrunes, 1976). Huger (2005) noted that the cytopathic process in the adult midgut, chronic infection and autodissemination render the adults “flying virus reservoirs,” providing a suitable strategy for regulating beetle populations.

Virus transmission thrives where male and female adults co-exist at dead standing palms, other breeding sites and possibly feeding sites (Bedford, 2013t, 2014; Zelazny and Alfiler, 1991). Horizontal viral transmission between adults likely occurs through 3 methods: (1) Copulation may not transmit the virus but may expose an uninfected adult to the fresh excrement of its infected partner, facilitating rapid per os entry. In the field, the number of infected mated females significantly exceeded that of unmated females (Zelazny, 1976). (2) Adults at the palm axils or similar feeding sites may transmit the virus during successive or simultaneous feeding. Adults defecate at the feeding sites, exposing the uninfected insects to the inoculum. However, due to rapid inactivation under dry conditions, only infrequent transmission of the virus may occur at feeding sites. Hochberg and Waage (1991) constructed a model to investigate the efficiency of various OrNV transmission pathways and indicated that the dominant route may be from infected to feeding adults. Zelazny and Alfiler (1991) indicated that transmission between young adults

at a feeding site may be attributed to mating at the site. (3) At breeding sites, virus survival is reduced, but the presence of the virus may be critical to its persistence in the environment and its utility for long-term control (Hochberg and Waage, 1991). Although several assumptions have been made regarding the spread of the virus, Bedford (2013t, 2014) noted that no peer-reviewed studies have confirmed the presence of virus in feeding holes, crowns or frond axils, and no evidence of copulation exists at these locations.

In the field, the virus may occur naturally at only a few breeding (oviposition) sites, but artificial OrNV inoculations at these sites can facilitate dissemination. The virus can be transmitted to adults from the inoculated breeding sites; however, this mode of transmission has limitations. Although older females frequently visit the breeding sites for oviposition, they rarely become infected, whereas younger females with higher probabilities of infection seldom visit the breeding sites (Zelazny, 1976). Although increased availability of decaying logs or other substrates can slow the spread of the virus, limited substrates ensure transmission sites. Surplus breeding sites reduce the chance for contact between infected and healthy adults. Therefore, strictly balancing the substrate availability could facilitate the spread of the disease and regulate *O. rhinoceros* populations (Zelazny and Alfiler, 1991).

Substrate availability may also play a role in spreading the virus. In the Philippines, Zelazny and Alfiler (1986) demonstrated that increasing the number of dead standing palms can increase viral spread, but additional stumps and felled logs do not enhance disease incidence. These observations may be location specific and may not extend to populations with different substrate preferences. Adults visiting the breeding sites may also become infected if the sites contain fresh virus inoculum from newly dead infected larvae; likewise, healthy larvae may become infected—although rarely—if exposed to the virus inoculum from the excrement of visiting beetles (Jackson *et al.*, 2005; Zelazny, 1973e; Zelazny, 1976; Zelazny and Alfiler, 1991).

Previous studies investigated other modes of OrNV transmission: Virus found on the cuticular surfaces of adult beetles rapidly inactivates under warm, dry conditions; therefore, transmission via cuticular contact is rare (Zelazny, 1976). Although Huger (1969) noted the possibility of vertical transmission, a study by Zelazny (1976) indicated that the pathogen cannot be vertically transmitted from larva to adult. Virus particles occur in the oviducts and oocytes of infected females, but most older infected females do not lay eggs, and if they oviposit, the larvae emerging from the surface-contaminated eggs are rarely infected (Zelazny, 1973a; Zelazny, 1976). Newly emerging adults are not vectors until they acquire the virus from other individuals, the environment or artificial inoculation (Zelazny and Alfiler, 1991).

Production, Maintenance and Storage of the Inoculum

The artificial cell line, DSIR-HA-1179, derived from the scarab, *Heteronychus arator* (F.) can be used to multiply OrNV (Crawford, 1982). Cell-culture-produced OrNV inocula are currently available and are used in several Pacific Island and Indian Ocean nations (Jackson *et al.*, 2010; Marshall, unpublished study, 2014). Guidelines from Jackson *et al.* (2010) suggest that pure culture vials are stable for several months if stored in a dark refrigerator upon receipt. Sealed virus inocula can also remain stable at room temperature (25–27 °C) for 6–8 weeks (Marshall, 2014). Once opened, culture vials should be used on the same day to avoid contamination. Deep-freeze storage is possible, but will reduce viral activity (Jackson *et al.*, 2010).

OrNV inocula derived from coconut rhinoceros beetles have often been used; Zelazny *et al.* (1987) described a procedure to produce OrNV inoculum in a laboratory with limited facilities. The Philippine Coconut Authority adopted a purified suspension technique using the guts of infected insects (initially inoculated using OrNV produced in the DSIR-HA-1179 cell line), glass permeation chromatography, sucrose density centrifugation and a final filtration method to seal the purified inoculum in sterile serum vials. The sealed vials could then be stored at room temperature for 2 weeks or refrigerated for 20 weeks.

During a field release study in Fiji, Bedford (1976o) suggested that the virus-packed cadavers of infected larvae could be stored indefinitely in deep freeze for later use as an inoculum source. However, OrNV is quickly inactivated when combined with a substrate and left open under ambient field conditions. To reconcile this discrepancy, Zelazny (1972) investigated the storage and inactivation of the virus using infected larvae ground and mixed into sawdust. After storage for 1 week, the viral activity decreased to 0.091% of its initial value, and after storage for 1 month, the inoculum was no longer infectious. The inactivation rate increased with increasing temperature and decreased with humidity (Zelazny, 1972). Incubation of OrNV solutions for 10 min at 50 °C severely reduced or completely eliminated viral activity (Zelazny, 1972). The OrNV or virus-containing substrates were fed to adult coconut rhinoceros beetles to produce and maintain the pathogen (Bedford, 1976o). Antifungal treatments can reduce contamination due to green muscardine fungus on the virus host (Bedford, 1976o).

Release of the Virus at Various Locations

Among the 37 species of entomopathogens used in classic biological control programs, OrNV, is considered the most successful microbe with the highest

number of global releases (18) and establishment at all locations introduced (Hajek *et al.*, 2007). This virus was released against *O. rhinoceros* in the South Pacific (Hammes and Monsarrat, 1974; Marschall, 1980), against *O. monoceros* in Seychelles, Tanzania and the Ivory Coast (Julia and Mariau, 1976; Lomer, 1986; Paul, 1985; Purrini, 1989) and re-released in OrNV-native locations (Mohan and Gopinathan, 1991; Mohan *et al.*, 1983; Zelazny, 1977a). The safety and environmental concerns with the pathogen were addressed prior to widespread OrNV introduction (Gourreau *et al.*, 1981).

Samoa: In 1967, OrNV was released in Manono and Savai'i in decaying sawdust under split coconut logs simulating a breeding site to attract adults. After 18 months, the beetle population nearly disappeared from Manono. In addition, infected larvae were recovered from untreated locations in Savai'i and another island, Upolu (Marschall, 1970). Although the virus strain originated in Malaysia and was cultured in Darmstadt, it was multiplied on native larvae in Samoa prior to release. The virus continued to spread without further assistance, allowing the recovery of coconut plantations in Samoa (Huger, 2005; Zelazny, 1973e). In 1975, a re-release program was established and the study confirmed that virus levels can be increased through a periodic re-release of OrNV (Marschall and Ioane, 1982).

Tokelau: In 1967, OrNV was released (Uili, 1980; Zelazny, 1977c). A few years after the initial release, the virus levels in the population plummeted necessitating re-releases in 1973 and 1974. Zelazny (1977c) reported a significant decline in the adult population 10 months after OrNV introduction.

Wallis Island: In 1970, OrNV was introduced causing adult beetle populations to decline 60–70% in 1 year.

Mauritius: In 1970, OrNV was introduced from Samoa, and in late 1974 a survey of the breeding grounds confirmed a decline in *O. rhinoceros* larvae (Monty, 1978). Overall, the surveys from 1973 to 1977 reported a 60–95% reduction in damage caused by *O. rhinoceros* (Hammes, 1978).

Tonga: In 1970, OrNV was introduced from Samoa. Epizootic levels developed in less than 5 months and the virus spread across the island in 15 months (Young, 1974). In 1978, approximately 7 years after the first release, surveys indicated a high percentage of infected breeding sites and adults, low levels of palm damage and reduced beetle populations (Young and Longworth, 1981). According to Bedford (1986), due to the lack of damage and persistence of OrNV, the virus was not re-released at this location.

Fiji: Multiple OrNV releases were made in Fiji from 1970 to 1974 (Bedford, 1976a, 1976o). Approximately 12–18 months later, a significant reduction in

palm damage was reported with approximately 57–68% of the beetles infected at this location. Bedford (1986) noted the same timeline for population decline in most release locations in the South Pacific.

Papua New Guinea In 1977, OrNV was imported from Samoa for field release in 1978 and 1979 (Gorick, 1980). Post-release monitoring revealed a minimum 8-month interval between OrNV release and the capture of a newly infected adult at this location. Trap surveys following the release suggested that the infection spread at a rate of 1 km per month (Gorick, 1980).

Maldives: From 1984–1985, OrNV was released in Meemu, Lhaviyani, North Ari, the Baa Atolls and a few islands close to Malé. Within a year of the release, beetle damage decreased by 25%, and the virus-infected adults increased to 50% with a 10% increase in the coconut yield (FAO, 1986).

Palau Islands: OrNV was imported from Samoa. After release, the virus became established in Babeldaob. In 1983, the virus was re-imported from Samoa and released in Peleliu among other locations due to an increase in *O. rhinoceros* population (Schreiner, 1989).

Sultanate of Oman: In 1989, virus-infected beetles were released (Kinawy, 2004). Two months later, OrNV was detected in approximately 41% of local beetles. Prior to release, approximately 85% of all palms were damaged; after release, the rate of damaged palms decreased to 48, 31, 17, 10, 6 and 4.2% in each of the first six years, respectively (Kinawy, 2004; Kinawy *et al.*, 2008).

Lakshadweep: In 1983, an OrNV isolate, OBV-KI, obtained from Kerala, India was released on Minicoy Island (Mohan *et al.*, 1989). After 19 months, the spathe damage to the coconut palms decreased by 93%, and after 3 years, a survey indicated that approximately 7.5% of the breeding sites on Minicoy were infected with the virus—a result comparable to that in Samoa after 4 years. After 2.5 years, nearly half of the beetles in trap catches were infected with OrNV (Mohan and Pillai, 1993a).

India: In 1985, OrNV-infected adults were released on oil palm plantations in Palode, Kerala, where the virus is indigenous (Dhileepan, 1994; Mohan *et al.*, 1983). Prior to the release, the indigenous virus infected approximately 60% of the beetles surveyed. After the supplementary OrNV release, the beetle damage in palms declined significantly during the first 3 years—70% damage was reduced to 20% by the third year. The damage appeared to reach equilibrium at the fourth year, and increased gradually until the final surveys in 1991. The decline in beetle attacks was not due to increased palm maturity, but to reduced virus inoculum levels at the sampled sites—as evidenced by a decrease in infected larvae at the breeding sites (Dhileepan, 1994). In 1989,

Biju *et al.* (1995) obtained similar results in 3–4-year-old coconut palms in OrNV-endemic Thrissur, Kerala indicating that re-release programs increase virus inoculum levels in the field. These studies confirmed the following: even in endemic areas, a re-release of OrNV can reduce palm damage, and post-release surveys should regularly monitor inoculum loads in the field.

Andaman Islands: In 1987, the Kerala isolate OBV-KI was introduced. Approximately 1.5 years after release, palm damage decreased an average of 60%; and after 3.5 years, damage decreased by 90% (Jacob, 1996). However, from 1999–2000, *O. rhinoceros* outbreaks were associated with an increase in coconut replanting programs throughout South Andaman. The outbreaks led to the re-release of infected beetles. Approximately 23 months after release, a 90% reduction in palm damage was observed at these locations with a three-fold reduction in the adult *O. rhinoceros* population (Prasad *et al.*, 2008a).

Malaysia: OrNV was first discovered in Malaysia, and although endemic, resurfaced in the 1990s as an important oil palm pest due to a ‘zero-burn’ policy on oil palm plantations. Moslim *et al.* (2005b; 2011c) demonstrated that the type-B strain of the virus was effective at the release sites.

OrNV Inoculation Methods for Field Release

The exact mechanism of transmission was unknown during the initial virus release programs in the South Pacific. The inoculation of the virus in the field occurred primarily through the application of OrNV at breeding sites. The imported virus strain was first multiplied in local host larvae in the laboratory to confirm and maintain virulence in the local populations. After death, the infected larval cadavers were stored in deep freeze for an extended period. Immediately prior to application, the cadavers were triturated to prepare a fresh virus suspension, which was then used to inoculate breeding sites. The treatment sites included natural breeding habitats, artificial compost and split coconut log heaps. Breeding-site OrNV inoculation proved successful in Samoa, Wallis, Mauritius and Tonga. The primary disadvantage of the method was the possible inactivation of the virus under ambient conditions outside the host; nevertheless, the breeding-site inoculation programs were successful, likely because large adult populations at the target site acquired the pathogen before inactivation (Bedford, 1976a; Burand, 2008; Hammes and Monsarrat, 1974; Huger, 1973; Marschall, 1970; Monty, 1974; Young, 1974). However, after the insects acquire the virus, an increase in beetle population may not always result in an increase in the virus inoculum at a release site (Marschall and Ioane, 1982; Zelazny, 1977c).

Once the role of adult beetles in the dissemination of the virus was discovered, all OrNV release programs shifted to the direct release of infected adults.

Oryctes rhinoceros adults can be collected in pheromone traps or from breeding heaps for infection and release (Bedford, 2013a; Jackson *et al.*, 2010; Ramle *et al.*, 2010). Previous studies investigated various techniques to maximize adult infection prior to release. For example, Bedford (1976o) dipped healthy adults in a virus suspension for 2–3 minutes and fed them an infected sawdust substrate for a day prior to their release at target sites in Fiji. Zelazny (1978) indicated that injecting adults with virus-infected hemolymph was more effective than submerging the adults in a virus suspension, but this method may not be suitable for large-scale releases. Marschall (1980) suggested another inoculation technique: The adult was fed infected substrates, and after 5–8 days, its infected midgut was dissected, macerated and prepared in a solution. Sugar was added to increase palatability, and the 10^{-4} to 10^{-5} g of solution was applied to individual beetle mouthparts. This technique was slightly modified at several release locations (Jackson *et al.*, 2010; Jacob, 1996; Mohan *et al.*, 1989; Ramle *et al.*, 2005b; Zelazny, 1978). A pause in pheromone trap operations for ~2 weeks after OrNV release is recommended for uniform distribution of the infected adults (Ramle *et al.*, 2005b). The virus dosage used to infect the adults for release may also impact the efficiency of an OrNV release program (Mohan and Pillai, 1993a; Prasad *et al.*, 2007; Prasad *et al.*, 2008c); however, no method currently exists to conclusively determine the virus dose (Bedford, 2013a, 2014).

Challenges to and Prospects for Implementation

At all introduced locations, the release of OrNV successfully reduced the impact of *O. rhinoceros* (Figure 8-10) and, in some cases, *O. monoceros* on palms. However, the reduction in *O. rhinoceros* population and the duration of impact varied with each release. The impact depends on factors intrinsic to *O. rhinoceros* and OrNV and their interactions with the environment, including the virulence of the isolate against beetle populations at the release location, the inoculation methods, dosage and activities that may impact the pre- and post-release *O. rhinoceros* density (Mohan *et al.*, 1989; Mohan and Pillai, 1993a; Zelazny and Alfiler, 1986; Zelazny *et al.*, 1990). For example, natural disasters, palm replanting and changes in plantation management such as the introduction of zero-burn policies can increase the availability of breeding sites. An abundant larval habitat may diminish opportunities for infected adults to contact healthy beetles. An increase in breeding sites also increases the proportion of healthy adults in the population leading to a reduced equilibrium of viral incidence (Mohan and Pillai, 1993a; Prasad *et al.*, 2008a; Ramle *et al.*, 2011c; Zelazny and Alfiler, 1991). This limitation encourages the development of strategies to boost the number of infected adults. Jackson *et al.* (2005) reviewed a ‘lure and infect’ autodissemination system for OrNV

release programs. Ideally, the aggregation pheromone, E4-MO, lures the adults, facilitates infection via a virulent OrNV isolate and allows escape for dissemination. However, execution requires a persistent and reliable virus inoculum, and the benefits of ‘lure and infect’ over ‘lure and kill’ have not been established (Jackson *et al.*, 2005).

Abiotic factors can also inhibit OrNV activity, which typically does not last long outside a host; dry, warm conditions can increase the OrNV inactivation rate (Zelazny, 1972, 1977c). According to Zelazny (1972) and Mohan *et al.* (1985), complete inactivation of the virus could occur after exposure to 56–70 °C for 10 minutes, although the time may be influenced by several intrinsic factors. In a field study, Gopal *et al.* (2002) demonstrated that OrNV infection in adults and larvae negatively correlates with the minimum temperature and positively correlates with the relative humidity.



Figure 8-10 *O. rhinoceros* damage in Fiji (A) before and (B) after OrNV release (images by Geoffrey Bedford posted with permission from the Annual Review of Entomology, Volume 58 © 2013 by Annual Reviews, <http://www.annualreviews.org>)

The 2 entomopathogens—green muscardine fungus and OrNV—were used simultaneously as biological control agents on several occasions to reduce coconut rhinoceros beetle damage. In 1969–1970, both pathogens were

released in Tonga to combat *O. rhinoceros*: The fungus did not significantly impact the pest population, but OrNV led to epizootic levels of infection, substantially reducing the number of beetles (Young, 1974). However, Bedford (1986) notes that the fungus may have established at the breeding sites and impacted the pest. Hochberg and Waage (1991) constructed a mathematical population model to understand the influence of various factors on the efficient dissemination of OrNV throughout a beetle population. In the model, the treatment of breeding sites with *M. anisopliae majus* was considered a persistent, density-independent factor in reducing the pest population. The model suggests that fungal application significantly impacts the larvae and emerging adults, but not feeding adults. Thus, the application of *M. anisopliae majus* may cause population instability in *O. rhinoceros* and lead to the gradual elimination of OrNV at the release site. In a later review, Bedford (2013a) argued that this negative interaction could only occur on small islands and should not be a problem on large landmasses because the diminishing OrNV inoculum will be replenished by immigrating infected adults. Furthermore, because *M. anisopliae majus* primarily affects the larvae and OrNV the adults, their simultaneous use may cause a rapid decline in the pest population. Interactions between OrNV and other microbes are not well understood; a preliminary study examined the impact of the enterobacterium, *Pseudomonas alcaligenes* Monias, on *O. rhinoceros* larvae in Kerala, India. An OrNV infection can stress the host and promote infection and septicemia by *P. alcaligenes*, which could gradually reduce the total OrNV inoculum in the environment. However, this stressor could also reduce the pest population (Murali and Alka, 2002). A survey conducted in Kerala, India from 1996–1999 demonstrated that 5 and 3% of the larvae died from viral and fungal infections, respectively, whereas 20% of the sampled larvae exhibited bacterial septicemia that interfered with the OrNV efficiency. The adults were not infected with the fungal and bacterial pathogens, but OrNV infection occurred in 22% of the sampled population (Gopal *et al.*, 2002). The interactions between the 3 microbes merit further investigation.

Host Resistance

Host plant resistance is not a current strategy against *O. rhinoceros*; however, evidence suggests a host preference by the beetle. Of 5 banana cultivars in Kerala, India, only the pseudostems ‘Nendran’ and ‘Njalipoovan’ were infested (Sivakumar and Mohan, 2013). Insect damage to banana fruits indicated that the beetle preferred smooth-skinned high-sugar-content varieties (Sharma and Gupta, 1988). Mature coconut palms are preferred to younger ones as are coconut cultivars from specific locations (Nirula *et al.*, 1952). Muthiah and Bhaskaran

(2000) screened coconut cultivars and found the lowest leaf damage (7.7%) on West Coast Tall, and the highest on Malaysian Yellow Dwarf (15.4%). For further information on preferred hosts, see *Adult Hosts* on page 4-8.

Integrated Pest Management (IPM)

The following strategies are those most commonly adopted to manage *O. rhinoceros* infestation (**Table 8-3**).

Table 8-3 Integrated pest management strategies against *O. rhinoceros*

Location	Summary	References
Guam	traps, phytosanitary measures, cypermethrin, surveys, outreach, preliminary studies using green muscardine fungus and OrNV	Moore (2012a)
India	repellents and abrasives at leaf axils, granular insecticides at leaf axils, chemicals at breeding sites, green muscardine fungus or botanicals at breeding sites, OrNV, mass trapping, mechanical control	Bhanu <i>et al.</i> (2012), Kumar and Ahmad (2008), Nair <i>et al.</i> (1998), Unnikrishnan Nair (2012), Varma (2013), Vidyasagar and Bhat (1991)
Pacific Islands	OrNV, green muscardine fungus, phytosanitary measures, chemicals	Catley (1969), Gressitt (1953), Huger (2005), Nirula <i>et al.</i> (1955), Zelazny (1975)
the Philippines	green muscardine fungus, phytosanitary measures, OrNV, chemical, mechanical, cultural, mass trapping	Philippine Coconut Authority (1998d, 2005), Zelazny and Alfiler (1987)
Malaysia	mass trapping, cover crops, OrNV, green muscardine fungus, synthetic pyrethroids, coal tar on frond rachis, mechanical control, trapping and removing breeding sites considered most important	Ahmad (2006), Chong <i>et al.</i> (1991), Darus and Basri (2000), Murphy (2007), Oehlschlager (2005)
the Middle East	mass trapping using pheromones and light traps, phytosanitary measures	El-Shafie (2014), Wright and Hajek (2009)

Bedford (2013t, 2014) noted that the pheromone traps widely used for control on oil palm plantations are only economical for monitoring endemic *O. rhinoceros* in coconut-growing South Pacific countries as long-term maintenance is expensive.

Educational outreach activities and active progress reports are also important to integrated pest management and eradication. In Guam and Hawaii, the recent outbreak of *O. rhinoceros* and the management strategies adopted were reported in online news channels and blogs (Kelman, 2007; Orth, 2007; Paco, 2013; Smith, 2014; Sweeney, 2008). This information also attracts feedback about the extent of adoption, the success of pest management methods and the socio-cultural concerns at these locations (Rumsey, 2012).

Regulatory Procedures

Use *Chapter 9 Regulatory Procedures* as a guide to the procedures that must be followed by regulatory personnel when conducting pest survey and control programs against *O. rhinoceros*.

Instructions to Officials

Agricultural officials must follow instructions for regulatory treatments or other procedures when authorizing the movement of regulated articles. Understanding the instructions and procedures is essential when explaining procedures to people interested in moving articles affected by the quarantine and regulations. Only authorized treatments can be used in line with labeling restrictions. During all field visits, ensure that proper sanitation procedures are followed.

Regulatory Actions and Authorities

After an initial suspect positive detection, an Emergency Action Notification may be issued to hold articles or facilities pending positive identification by a USDA–APHIS–PPQ-recognized authority and/or further instruction from the PPQ deputy administrator. If necessary, the deputy administrator will issue a letter directing PPQ field offices to initiate specific emergency action under the Plant Protection Act until emergency regulations can be published in the *Federal Register*.

The Plant Protection Act of 2000 (Statute 7 USC 7701-7758) provides the authority for emergency quarantine action. This provision is for interstate regulatory action only; intrastate regulatory action is provided under state authority.

State departments of agriculture normally work in conjunction with federal actions by issuing their own parallel hold orders and quarantines for intrastate movement. However, if the U.S. Secretary of Agriculture determines that an extraordinary emergency exists and that state measures are inadequate, intrastate regulatory action can be taken provided that the governor of the state has been

consulted and a notice has been published in the *Federal Register*. If intrastate action cannot or will not be taken by a state, PPQ may find it necessary to quarantine an entire state.

PPQ works in conjunction with state departments of agriculture to conduct surveys, enforce regulations and take control actions. PPQ employees must obtain permission of the property owner before entering private property. Under certain situations during a declared extraordinary emergency or if a warrant is obtained, PPQ can enter private property without owner permission. PPQ prefers to work with the state to facilitate access when permission is denied; however, each state government has varying authorities regarding entering private property.

A General Memorandum of Understanding (MOU) exists between PPQ and each state that specifies various areas in which PPQ and the state department of agriculture cooperate. For clarification, check with your State Plant Health Director (SPHD) or State Plant Regulatory Official (SPRO) in the affected state.

Tribal Governments

USDA–APHIS–PPQ also works with federally recognized Native American tribes to conduct surveys, enforce regulations and take control actions. Each tribe stands as a separate governmental entity (sovereign nation) with powers and authorities similar to state governments. Permission is required to enter and access tribal lands.

Executive Order 13175, Consultation and Coordination with Indian and Tribal Governments, states that agencies must consult with Native American tribal governments about actions that may have substantial direct effects on tribes. Whether an action is substantial and direct is determined by the tribes. Effects are not limited to tribal land boundaries (reservations) and may include effects on off-reservation land or resources which tribes customarily use or even effects on historic or sacred sites in states where tribes no longer exist.

Consultation is a specialized form of communication and coordination between the federal and tribal governments. Consultation must be conducted early in the development of a regulatory action to ensure that tribes have opportunity to identify resources that may be affected by the action and to recommend the best ways to take actions on tribal lands or affecting tribal resources. Communication with tribal leadership follows special communication protocols. For more information, contact PPQ's Tribal Liaison.

To determine if there are federally recognized tribes in a state, contact the State Plant Health Director (SPHD). To determine if there are sacred or historic sites in

an area, contact the State Historic Preservation Officer (SHPO). For clarification, check with your SPHD or State Plant Regulatory Official (SPRO) in the affected state.

Overview of Regulatory Program after Detection

Once an initial US detection is confirmed, holds will be placed on the property by the issuance of an Emergency Action Notification. Immediately put a hold on the property to prevent the removal of any host plants of the pest.

Trace-back and trace-forward investigations from the property will determine the need for subsequent holds for testing and/or further regulatory actions. Further delimiting surveys and testing will identify positive properties requiring holds and regulatory measures.

Record-Keeping

Record-keeping and documentation are important for any holds and subsequent actions taken. Rely on receipts, shipping records and information provided by the owners, researchers or manager for information on destination of shipped plant material, movement of plant material within the facility and any management (cultural or sanitation) practices employed.

Keep a detailed account of the numbers and types of plants held, destroyed and/or requiring treatments in control actions. Consult a master list of properties, distributed with the lists of suspect nurseries based on trace-back and trace-forward investigations, or facilities within a quarantine area. Draw maps of the facility layout to located suspect plants and/or other potentially infested areas. When appropriate, take photographs of the symptoms, property layout and document plant propagation methods, labeling and any other information that may be useful for further investigations and analysis.

Keep all written records filed with the Emergency Action Notification documents, including copies of sample submission forms, documentation of control activities and related state-issued documents if available.

Issuing an Emergency Action Notification

Issue an Emergency Action Notification to hold all host plant material at facilities that have plant material suspected of direct or indirect connection to positive confirmations. Once an investigation determines the plant material is not infested

or testing determines there is no risk, the material may be released and the release documented on the EAN.

Establishing a Federal Regulatory Area or Action

Regulatory actions undertaken using Emergency Action Notifications continue to be in effect until the prescribed action is carried out and documented by regulatory officials. These may be short-term destruction or disinfestation orders or longer term requirements for growers that include prohibiting the planting of host crops for a time. Over the long term, producers, shippers and processors may be placed under compliance agreements and permits issued to move regulated articles out of a quarantine area or property under an EAN.

Results analyzed from investigations, testing and risk assessment will determine the area to be designated for federal and parallel state regulatory actions. Risk factors will consider positive testing, positive associated and potentially infested exposed plants. Boundaries drawn may include a buffer area determined using risk factors and epidemiology.

Regulatory Records

Maintain standardized regulatory records and databases in sufficient detail to carry out an effective, efficient and responsible regulatory program.

Use of Chemicals

The PPQ *Treatment Manual* and these guidelines identify the authorized chemicals and describe the methods and rates of application and any special instructions. For further information refer to [Chemical Control](#) on page 8-14. Agreement by PPQ is necessary before using any chemical or procedure for regulatory purposes. No chemical can be recommended that is not specifically labeled for this pest. If a formulation is not labeled for the necessary use, one can request a federal crisis or quarantine exemption from the EPA under section 18 of FIFRA.

Literature Cited

- Ahmad, A. H. 2006. Final report on control of rhinoceros beetle (*Oryctes rhinoceros*) in a zero burning replanted oil palm area felda plantation. Pusat Pengajian Sains Kajihayat, USM, 11800 Pulau, Pinang, Lepar Utara, Pahang.
- Al-Habshi, K. A., S. A. Ba-Angood, and S. O. Al-Baiti. 2006. The occurrence of the date palm borer *Oryctes rhinoceros* (Linnaeus) in light traps in Wadi Hadramout in 2002. University of Aden Journal of Natural and Applied Sciences 10(3):419-426.
- Alam, M. Z. 1975. Entomological problems of agriculture in Bangladesh. PANS Pest Articles & News Summaries 21(4):380-383.
- Allou, K., J. P. Morin, P. Kouassi, F. H. N'Klo, and D. Rochat. 2006. *Oryctes monoceros* trapping with synthetic pheromone and palm material in Ivory Coast. Journal of Chemical Ecology 32(8):1743-1754.
- Ambethgar, V. 2009. Potential of entomopathogenic fungi in insecticide resistance management (IRM): A review. Journal of Biopesticides 2(2):177-193.
- Arnett, R. H., T. M. C. Jr, P. E. Skelley, and J. H. Frank. 2002. American Beetles, Volume II: Polyphaga: Scarabaeoidea through Curculionoidea. CRC Press. 1-861 pp.
- Barber, I. A., T. P. McGovern, M. Beroza, C. P. Hoyt, and A. Walker. 1971. Attractant for the Coconut Rhinoceros Beetle. Journal of Economic Entomology 64(5):1041-1044.
- BCRL. n.d. RB-Lure for Management of Rhinoceros Beetle. Bio-Control Research Laboratories, Division of Pest Control India.
- Beaudoin-Ollivier, L., R. N. B. Prior, and S. Laup. 1998. A field key to identify some rhinoceros and other beetle larvae breeding in coconut palm habitats in Papua New Guinea. PNG J. Agric. For. Fish 41:1-15.
- Beaudoin-Ollivier, L., R. N. B. Prior, and S. Laup. 2000. Simplified field key to identify larvae of some rhinoceros beetles and associated scarabs (Coleoptera: Scarabaeoidea) in Papua New Guinea coconut developments. Annals of the Entomological Society of America 93(1):90-95.
- Bedford, G. O. 1974. Descriptions of the larvae of some rhinoceros beetles (Col., Scarabaeidae, Dynastinae) associated with coconut palms in New Guinea. Bulletin of Entomological Research 63(3):445-472.
- Bedford, G. O. 1975. Trap catches of the coconut rhinoceros beetle *Oryctes rhinoceros* (L.)

- (Coleoptera, Scarabaeidae, Dynastinae) in New Britain. Bulletin of Entomological Research 65(3):443-451.
- Bedford, G. O. 1976a. Mass rearing of the coconut palm rhinoceros beetle for release of virus. PANS 22(1):5-10.
- Bedford, G. O. 1976b. Observations on the biology and ecology of *Oryctes rhinoceros* and *Scapanes australis* (Coleoptera: Scarabaeidae: Dynastinae): Pests of coconut palms in Melanesia. Australian Journal of Entomology 15(3):241-251.
- Bedford, G. O. 1976c. The use of a virus against the coconut palm rhinoceros beetle in Fiji. Bulletin du Pacifique Sud 27(1):19-27.
- Bedford, G. O. 1980. Biology, ecology, and control of palm rhinoceros beetles. Annual Review of Entomology 25(1):309-339.
- Bedford, G. O. 1986. Biological control of the rhinoceros beetle (*Oryctes rhinoceros*) in the South Pacific by baculovirus. Agriculture, Ecosystems & Environment 15(2-3):141-147.
- Bedford, G. O. 2013a. Biology and management of palm dynastid beetles: Recent advances. Pages 353-+ In M. R. Berenbaum, (ed.). Annual Review of Entomology. Annual Reviews, Palo Alto.
- Bedford, G. O. 2013t. Long-term reduction in damage by rhinoceros beetle *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae: Dynastinae) to coconut palms at Oryctes Nudivirus release sites on Viti Levu, Fiji. African Journal of Agricultural Research 8(49):6422-6425.
- Bedford, G. O. 2014. External review and personal communication for the preparation of *Oryctes rhinoceros* New Pest Response Guidelines. Personal communication to G. R. Pallipparambil on from
- Berringer, D. 2007. Coconut rhinoceros beetle eradication program, Guam. Environmental assessment. EA Number: GU-08-1. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine.
- Bhanu, K. R. M., and Chandrasekharaiah. 2013. Pheromone technology: an ecofriendly approach for coconut pest management. Indian Coconut Journal 56(3):29-31.
- Bhanu, K. R. M., Jayanth, K. P., T. M. M., and M. S. Prabhakara. 2012. Integrated management of major coconut pests using pheromone lures. Cord 28(2).
- Bhatnagar, S. P. 1971. New records of the Dynastides pests from Rajasthan. Labdev Journal of Science and Technology 9(3/4):232-233.
- Bhide, S. G., and P. D. Patil. 2005. Effectiveness on *Metarhizium anisopliae* (METSCH.) Sorokin against *Oryctes* grubs. Pestology 29(5):28-30.
- Biju, B., K. S. Devi, T. K. Dangar, and B. Sathiamma. 1995. Biological suppression of *Oryctes rhinoceros* by re-release of *Baculovirus oryctes* in an infected contiguous area. Journal of Plantation Crops 23(1):62-63.
- Bischoff, J. F., S. A. Rehner, and R. A. Humber. 2009. A multilocus phylogeny of the *Metarhizium*

- anisopliae* lineage. *Mycologia* 101(4):512-530.
- Brands, S. J. 1989-2005. *Systema Naturae* 2000. Amsterdam, The Netherlands. Accessed, <http://sn2000.taxonomy.nl/>.
- Burand, J. P. 2008. Insect viruses: nonoccluded. Pages 144-148 In B. W. J. Mahy and M. H. V. V. Regenmortel, (eds.). *Encyclopedia of Virology* (Third Edition). Academic Press, Oxford.
- CABI. 2014a. Crop Protection Compendium. The world's most comprehensive site for crop protection information. CAB International, Wallingford , UK. Accessed on 22 April 2014, www.cabi.org/cpc.
- CABI. 2014b. *Oryctes rhinoceros*.
- Campbell, R. K. 2011. Coconut rhinoceros beetle eradication program on Guam. Environmental assessment. December 2011. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine.
- CAPS. 2014. 2015 National Survey Guidelines. Accessed
- Catley, A. 1969. The coconut rhinoceros beetle *Oryctes rhinoceros* (L.) [Coleoptera: Scarabaeidae: Dynastinae]. *Pest Articles & News Summaries* 15(1):18-30.
- Chakravarthy, A. K., M. Chandrashekharaiyah, S. B. Kandakoor, and D. N. Nagaraj. 2014. Efficacy of aggregation pheromone in trapping red palm weevil (*Rhynchophorus ferrugineus* Olivier) and rhinoceros beetle (*Oryctes rhinoceros* Linn.) from infested coconut palms. *Journal of Environmental Biology* 35:479-484.
- Cherian, M. C., and K. P. Anantanarayanan. 1939. Studies on the coconut palm beetle (*Oryctes rhinoceros* Linn.) in South India. *Indian Journal of Agricultural Sciences* 9((3)):541-559.
- Chong, K. K., P. A. C. Ooi, and H. C. Tuck. 1991. *Crop pests and their management in Malaysia*. Tropical Press.
- Christie, D. 2014. *Oryctes rhinoceros* host data. Personal communication to G. R. Pallipparambil on 15 July 2014, from
- Coconut Development Board. 2013. India marches to the first position in coconut production. Monthly operations in coconut gardens, March. *Indian Coconut Journal*.
- Cohic, F. 1950. Insect Pests in the Wallis Islands and Futuna. Technical Papers. South Pacific Commission.
- Crawford, A. M. 1981. Attempts to obtain *Oryctes* baculovirus replication in three insect cell cultures. *Virology* 112(2):625-633.
- Crawford, A. M. 1982. A coleopteran cell line derived from *Heteronychus arator* (Coleoptera: Scarabaeidae). *In Vitro-Plant* 18(10):813-816.
- Crawford, A. M. 1988. Detection of baculovirus infection in rhinoceros beetle (*Oryctes rhinoceros*) and the purification and identification of virus strains. Integrated Coconut Pest Control Project Annual report.

- Crawford, A. M., K. Ashbridge, C. Sheehan, and P. Faulkner. 1985. A physical map of the *Oryctes baculovirus* genome. *Journal of General Virology* 66(12):2649-2658.
- Crawford, A. M., P. Faulkner, and J. Kalmakoff. 1978. Comparison of solid-phase radioimmunoassays for baculoviruses. *Applied and environmental microbiology* 36(1):18-24.
- CRB TWG. 2014. Report: Coconut Rhinoceros Beetle Project, Subject Matter Expert Meeting, 1/22-23/14 DRAFT V1. Coconut Rhinoceros Beetle Technical Working Group (CRB TWG). 17 pp.
- Croizer, G., and P. Monsarrat. 1974. Immunological diagnosis of a virus disease of the beetle *Oryctes rhinoceros*. *Entomophaga* 19(1):115-116.
- Crowson, R. A. 1981. The biology of the Coleoptera (abstract). Academic Press Inc.
- Cumber, R. A. 1957. Ecological studies of the rhinoceros beetle *Oryctes rhinoceros* (L.) in Western Samoa. Technical Papers. South Pacific Commission (107).
- Darus, A., and M. W. Basri. 2000. Intensive IPM for management of oil palm pests. *Oil Palm Bull* 41:1-14.
- Darwis, M. 1990. Minimum effective concentration of *Metarhizium anisopliae* to control *Oryctes rhinoceros* larvae. *Pemberitaan Penelitian Tanaman Industri* 15(4):133-136.
- Daud, I. D. 2007. Spread of coconut beetle pest *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) in district Mattirobulu Kabupaten Pinrang.
- Desmier, R., H. Asmady, and P. Sudharto. 2001. New improvement of pheromone traps for the management of the rhinoceros beetle in oil palm plantations. Pages 624-632 in Cutting-edge technologies for sustained competitiveness: Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference, Kuala Lumpur, Malaysia, 20-22 August 2001. Malaysian Palm Oil Board (MPOB).
- Dharmaraju, E. 1980. Pest problems in Niue. *Alafua agricultural bulletin* 5(3):24-26.
- Dhileepan, K. 1991. Insects associated with oil palm in India. *FAO Plant Protection Bulletin* 39(2-3):94-99.
- Dhileepan, K. 1992. Insect pests of oil palm (*Elaeis guineensis*) in India. *Planter (Malaysia)* 68(793):183-191.
- Dhileepan, K. 1994. Impact of release of *Baculovirus oryctes* into a population of *Oryctes rhinoceros* in an oil palm plantation in India. *Planter* 70(819):255-266.
- Dhondt, A. A., T. P. McGovern, and M. Beroza. 1976. Effect of juvenile hormone mimics on the coconut rhinoceros beetle. *Journal of Economic Entomology* 69(4):427-428.
- Doane, R. W. 1913. How *Oryctes rhinoceros*, a Dynastid beetle, uses its horn. *Science*:883.
- Eberle, K. E., J. T. Wennmann, R. G. Kleespies, and J. A. Jehle. 2012. Chapter II - Basic techniques in insect virology. Pages 15-74 In L. A. Lacey, (ed.). *Manual of Techniques in Invertebrate Pathology* (Second Edition). Academic Press, San Diego.

- El-Sayed, A. M. 2007. Pherobase: Semiochemicals of *Oryctes rhinoceros*, the coconut rhinoceros beetle. Accessed on 14 December 2007, <http://www.pherobase.com/>.
- El-Shafie, H. A. F. 2014. Overview of the biology and management of date palm Dynastid beetles (Coleoptera: Scarabeidae, Dynastinae).
- El Damir, M. 2006. Effect of growing media and water volume on conidial production of *Beauveria bassiana* and *Metarhizium anisopliae*. Journal of Biological Sciences 6(2):269-274.
- Elfers, S. C. 1988. Element stewardship abstract for *Casuarina equisetifolia*. The Nature Conservancy. Unpublished report prepared for The Nature Conservancy on Australian pine. Winter Park, FL. Accessed from <http://www.invasive.org/gist/esadocs/documents/casuequ.pdf> on 25 March 2014 30(2010):12.
- Endrödi, S. 1985. Tribe V: Oryctini. Pages 514-531 In K. A. Spencer (Ed.), The Dynastinae of the World. Dr. W. Junk Publishers.
- EPA. 2003. Health effects support document for naphthalene. Washington, DC. Accessed on 15 April 2014
- EPA. 2008. Revised reregistration eligibility decision for cypermethrin. Accessed on 15 April 2014, http://www.epa.gov/opprrd1/reregistration/REDs/cypermethrin_revised_red.pdf.
- EPA. 2011. Carbofuran cancellation process. Pesticide registration status. Accessed on 14 April 2014, http://www.epa.gov/opprrd1/reregistration/carbofuran/carbofuran_noic.htm.
- EPA. 2014. The phaseout of methyl bromide and critical use exemption information. Accessed on 17 April 2014, <http://www.epa.gov>.
- Fakayode, O. S., and A. A. A. Ugwumba. 2013. Effects of replacement of fishmeal with palm grub (*Oryctes rhinoceros* (Linnaeus, 1758)) meal on the growth of *Clarias gariepinus* (Burchell, 1822) and *Heterobranchus longifilis* (Valenciennes, 1840) fingerlings. Journal of Fisheries and Aquatic Science 8(1):101-107.
- FAO. 1986. Maldives. FAO project statement on biological control of rhinoceros beetle. Quarterly newsletter, Asia and Pacific Plant Protection Commission, Food Agricultural Organization, Thailand 29(3):46-49.
- FAOSTAT. 2014. Import and export information of coconut and oil palm products in United States. Accessed on 5 May 2014, http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*/E.
- Fargues, J. F., and P. H. Robert. 1983. Effects of passaging through scarabeid hosts on virulence and host specificity of two strains of the entomopathogenic hyphomycete *Metarhizium anisopliae*. Canadian Journal of Microbiology 29(5):576-583.
- Faridah, S., Y. Shirai, A. R. Gayah, and A. Oshibe. 2003. Simultaneous determination of pyrethroid insecticides in oil palm frond (OPF) by capillary column gas chromatograph. Forages and Feed Resources in Commercial Livestock Production Systems:198.
- Fee, C. G. 1997. The bioefficacy of the aggregation pheromone in mass trapping of rhinoceros beetles (*Oryctes rhinoceros* L.) in Malaysia. Planter 73(852):119-127.

- Fernando, L. C. P., P. Kanagaratnam, and N. K. Narangoda. 1995. Some studies on the use of *Metarrhizium anisopliae* (Metsch.) Sor. for the control of *Oryctes rhinoceros* in Sri Lanka. COCOS 10(94/95):46-52.
- Ferron, P., P. H. Robert, and A. Deotte. 1975. Susceptibility of *Oryctes rhinoceros* adults to *Metarrhizium anisopliae*. Journal of Invertebrate Pathology 25(3):313-319.
- Gallego, C. E., and E. D. Aterrado. 2003. In-vivo production of green muscardine fungus. Los Baños, Philippines. Accessed on 30 April 2014, www.pcaarrd.dost.gov.ph.
- Garlovsky, D. F., B. Zelazny, and C. South Pacific. 1971. External morphology of *Oryctes rhinoceros*. South Pacific Commission, Noumea, New Caledonia. 8, 2 p. pp.
- Gassouma, M. S. 2004. Pests of the date palm (*Phoenix dactylifera*). Proceedings of the regional workshop on date palm development in the GCC countries of the Arabian Peninsula, Abu Dhabi.
- GBIF. 2014. Global Biodiversity Information Facility Data Portal. Copenhagen. Accessed on 3 April 2014, <http://www.gbif.org>.
- George, E., and C. Kurian. 1970. Fungus to fight black beetle. Coconut bulletin 1(1).
- Giblin-Davis, R. M., F. W. Howard, D. Moore, and R. G. Abad. 2001. Borers of palms. Insects on palms:267-304.
- Gopal, M., and A. Gupta. 2001. The green muscardine fungus '*Metarrhizium anisopliae*' as mycoinsecticide for control of rhinoceros beetle of coconut palm. Indian Coconut Journal 31(11):4-6.
- Gopal, M., A. Gupta, B. Sathiamma, and C. P. R. Nair. 2002. Microbial pathogens of the coconut pest *Oryctes rhinoceros*: influence of weather factors on their infectivity and study of their coincidental ecology in Kerala, India. World Journal of Microbiology & Biotechnology 18:417-421.
- Gopal, M., A. Gupta, and G. V. Thomas. 2006. Prospects of using *Metarrhizium anisopliae* to check the breeding of insect pest, *Oryctes rhinoceros* L. in coconut leaf vermicomposting sites. Bioresource Technology 97(15):1801-1806.
- Gope, B., and B. Prasad. 1983. Preliminary observation on the nutritional value of some edible insects of Manipur. Journal of Advanced Zoology 4(1):55-61.
- Gorick, B. D. 1980. Release and establishment of the baculovirus disease of *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae) in Papua New Guinea. Bulletin of Entomological Research 70(03):445-453.
- Gourreau, J. M., C. Kaiser, and P. Montsarrat. 1981. Study on the possible pathogenic effect of baculovirus of *Oryctes* on cell cultures of vertebrates in continuous lines. Annales de l'Institut Pasteur / Virologie 132(3):347-355.
- Gressitt, J. L. 1953. The Coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. Bernice P. Bishop Museum, Honolulu, HI. 1-157 pp.

- Gries, G., R. Gries, A. L. Perez, A. C. Oehlschlager, L. M. Gonzales, H. D. Pierce Jr, M. Zebeyou, and B. Kouame. 1994. Aggregation pheromone of the African rhinoceros beetle, *Oryctes monoceros* (Olivier)(Coleoptera: Scarabaeidae). Zeitschrift fur Naturforschung C-A Journal of Biosciences 49(5):363-366.
- Guaminsects.net. 2007a. Guam coconut rhinoceros beetle eradication plan (Draft). Accessed, http://guaminsects.net/uogces/kbwiki/index.php?title=Guam_Coconut_Rhinoceros_Beetle_Eradication_Plan.
- Guaminsects.net. 2007b. Movement of palms, logs, and rotting vegetation from Tumon Bay area may prevent planned eradication of the coconut rhinocerus beetle, a major pest of palms. Press Release. Mangilao, Guam: University of Guam Cooperative Extension Service. Retrieved December 14, 2007, from
- Gunawardena, N. E. 2014. Eco friendly pest control with semiochemicals. 'Towards Transdisciplinary Research Culture'. First Ruhuna International Science and Technology Conference, Matara 81000, Sri Lanka. January 22-23, 2014.
- Hajek, A. E., M. L. McManus, and I. Delalibera Júnior. 2007. A review of introductions of pathogens and nematodes for classical biological control of insects and mites. Biological control 41(1):1-13.
- Hallett, R. H. 1996. Aggregation pheromones of coleopteran pests of palms, Science: Biological Sciences Department.
- Hallett, R. H., C. Oehlschlager, and J. H. Borden. 1999. Pheromone trapping protocols for the Asian palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). International Journal of Pest Management 45(3):231-237.
- Hallett, R. H., A. L. Perez, G. Gries, R. Gries, H. D. Pierce, Jr., J. Yue, A. C. Oehlschlager, L. M. Gonzalez, and J. H. Borden. 1995. Aggregation pheromone on coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae). Journal of Chemical Ecology 21(10):1549-1570.
- Hamid, N. H., M. Ramle, H. Salim, W. Mohd Basri, K. Norman, and S. Hamzah. 2005. Powder formulation of *Metarhizium anisopliae*, its stability and effects against *Oryctes* beetles tested in laboratory and small scale field trial. Proceedings of the PIPOC 2005 International Palm Oil Congress (Agriculture, Biotechnology and Sustainability), Kuala Lumpur Convention Centre, Malaysia.
- Hammes, C. 1978. Estimation of the effectiveness of *Rhabdionvirus oryctes* (Huger) for controlling *Oryctes rhinoceros* (L.) by means of a study of the changes in damage on coconut in Mauritius. Revue Agricole et Sucriere de l'Ile Maurice 57(1):4-18.
- Hammes, C., and P. Monsarrat. 1974. Research on *Oryctes rhinoceros* L. Cahiers O.R.S.T.O.M., Biologie (22):44-111.
- Hara, A. 2014. Visit to Guam
- Hawaii Department of Agriculture. 2014a. Coconut rhinoceros beetle found at Barbers point. Department of Agriculture, State of Hawaii; United States Department of Agriculture,

Honolulu, HI.

- Hawaii Department of Agriculture. 2014e. Destructive beetles found on Oahu coconut trees. State of Hawaii, Department of Agriculture. Accessed on 3 March 2014, <http://hdoa.hawaii.gov>.
- Hawaii Department of Agriculture. 2014h. New pest advisory for coconut rhinoceros beetle, *Oryctes rhinoceros* (Linnaeus) (Coleoptera: Scarabaeidae). Accessed on 2 May 2014, <http://hdoa.hawaii.gov/pi/files/2013/01/npa-CRB-5-1-14.pdf>.
- Hawaii Department of Agriculture. 2014j. No rhino pamphlet. Honolulu coconut rhinoceros beetle eradication. Department of Agriculture, State of Hawaii; United States Department of Agriculture.
- Hawaii Invasive Species Council. 2014a. Weekly CRB Update: 1-9 May 2014. Activities to eradicate the coconut rhinoceros beetle on Oahu.
- Hawaii Invasive Species Council. 2014b. Weekly CRB Update: 3-7 February 2014. Activities to eradicate the coconut rhinoceros beetle on Oahu.
- Hawaii Invasive Species Council. 2014h. Weekly CRB Update: 22-28 March 2014. Activities to eradicate the coconut rhinoceros beetle on Oahu.
- Hawaii Invasive Species Council. 2014l. Weekly CRB Update: April 2014. Activities to eradicate the coconut rhinoceros beetle on Oahu.
- Hinckley, A. D. 1967. Associates of the coconut rhinoceros beetle in Western Samoa. Pacific Insects 9(3):505-511.
- Hinckley, A. D. 1973. Ecology of the coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) (Coleoptera:- Dynastidae). Biotropica 5(2):111-116.
- Hochberg, M. E., and J. K. Waage. 1991. A Model for the biological control of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) by means of pathogens. Journal of Applied Ecology 28(2):514-531.
- Hosoya, T. 2011. Records of the exotic and pest beetle *Oryctes rhinoceros* (Coleoptera, Scarabaeidae, Dynastinae) from Takara Island in the Tokara Islands. Elytra 1(2):209-210.
- Howard, F. 2001. Insect pests of palms and their control. Pesticide Outlook 12(6):240-243.
- Hoyt, C. P. 1963. Investigations of rhinoceros beetles in West Africa. Pacific Science 17(4):444-451.
- Huger, A. M. 1966. A virus disease of the Indian rhinoceros beetle, *Oryctes rhinoceros* (linnaeus), caused by a new type of insect virus, *Rhabdionvirus oryctes* gen. n., sp. n. Journal of Invertebrate Pathology 8(1):38-51.
- Huger, A. M. 1969. On the symptomatology of 'Malaya disease', a virosis of the Indian rhinoceros beetle *Oryctes rhinoceros* (Linnaeus). Tagungsberichte, Deutsche Akademie der Landwirtschaftswissenschaften zu Berlin (80):421-429.
- Huger, A. M. 1973. Groundwork for the biological control of the Indian rhinoceros beetle, *Oryctes rhinoceros* (L.) with *Rhabdionvirus oryctes*: histopathology of the disease in the beetles.

- Zeitschrift fur Angewandte Entomologie 72(3):309-319.
- Huger, A. M. 2005. The *Oryctes* virus: Its detection, identification, and implementation in biological control of the coconut palm rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Journal of Invertebrate Pathology 89(1):78-84.
- Hurpin, B., and M. Fresneau. 1973. Laboratory studies on fecundity factors in *Oryctes monoceros* Ol. and *O. rhinoceros* L. (Col. Scarabaeidae). Annales de la Societe Entomologique de France 9(1):89-117.
- Indiravathi, G., M. Rajamannar, and A. Sujatha. 2001. Biology of rhinoceros beetle, *Oryctes rhinoceros* L. in coastal Andhra Pradesh. Journal of Applied Zoological Researches 12(1):14-18.
- ISCA. 2006. Instruction sheet SPLAT-RB lure for control of the rhinoceros beetle *Oryctes rhinoceros*. ISCA Technologies. 5 pp.
- Jackson, T., S. N. Lal, K. Tuapola, S. Prasad, J. Monk, N. Richards, and S. Marshall. 2010. Biological control of rhinoceros beetle in the Pacific using *Oryctes* virus, Operational protocols (Version A). 36 pp.
- Jackson, T. A. 2009. The use of Oryctes virus for control of rhinoceros beetle in the Pacific Islands. Pages 133-140 Use of Microbes for Control and Eradication of Invasive Arthropods. Springer.
- Jackson, T. A. 2014. External review and personal communication for the preparation of *Oryctes rhinoceros* New Pest Response Guidelines. Personal communication to G. R. Pallipparambil on from
- Jackson, T. A., A. M. Crawford, and T. R. Glare. 2005. *Oryctes* virus—Time for a new look at a useful biocontrol agent. Journal of Invertebrate Pathology 89(1):91-94.
- Jacob, M. 2000. Phoretic mite as biocontrol agent of rhinoceros beetle, *Oryctes rhinoceros*. Journal of Applied Zoological Researches 11(2/3):87-89.
- Jacob, M., M. Java, and M. M. Oommen. 2008. Development and structure of accessory sex gland of male *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Uttar Pradesh Journal of Zoology 28(3):281-287.
- Jacob, T. K. 1996. Introduction and establishment of baculovirus for the control of rhinoceros beetle *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) in the Andaman Islands (India). Bulletin of Entomological Research 86(3):257-262.
- Jacob, T. K., and B. S. Bhumannavar. 1991. The coconut rhinoceros beetle *Oryctes rhinoceros* L.—its incidence and extent of palm damage in the Andaman and Nicobar Islands (India). International Journal of Pest Management 37(1):80-84.
- Jayanth, K. P., M. T. Mathew, G. B. Narabenchi, and K. R. M. Bhanu. 2009. Reproductive status of *Oryctes rhinoceros* females captured in aggregation pheromone traps. Indian Coconut Journal 52(2):17-20.
- Julia, J. F., and D. Mariau. 1976. Research on *Oryctes monoceros* in Ivory Cost. Trial of biological

- control by virus *Rhabdionvirus oryctes*. Oleagineux.
- Kalidas, P. 2004. Effects of abiotic factors on the efficiency of rhinoceros beetle pheromone, oryctalure, in the oil palm growing areas of Andhra Pradesh. Planter 80(935):103-115.
- Kamarudin, N. H., and W. Mohd Basri. 1997. Status of rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) as a pest of young oil palm in Malaysia. Planter 73(850):5-21.
- Kao, S. S., W. Hsiao, and Y. S. Tsai. 2012. Research, Development and Application of Fungal Insecticides in Taiwan. 植物保護學會會刊 54(3):65-75.
- Kartesz, J. T. 2013. Floristic Synthesis of North America, Version 1.0. The Biota of North America Program (BONAP). Accessed on 2013, <http://www.bonap.net/tdc>.
- Kegley, S. E., B. R. Hill, S. Orme, and A. H. Choi. 2010. PAN pesticide database. Pesticide Action Network, North America (San Francisco, CA, 2010). Accessed on 11 April 2014, <http://www.pesticideinfo.org>.
- Kelman, B. 2007. Volunteers take on rhino beetle. Pacific Daily News. 19 November 2007, <http://www.guampdn.com/apps/pbcs.dll/article?AID=/20071119/NEWS01/711190308/10>.
- Kepler, R. M., and S. A. Rehner. 2013. Genome-assisted development of nuclear intergenic sequence markers for entomopathogenic fungi of the *Metarhizium anisopliae* species complex. Molecular ecology resources 13(2):210-217.
- Khanjani, M., B. Ghaedi, and E. A. Ueckermann. 2013. New species of *Hypoaspis* Canestrini and *Coleolaelaps* Berlese (Mesostigmata: Laelapidae) associated with *Polyphylla olivieri* Castelnau (Coleoptera: Scarabaeidae) in Iran. Zootaxa 3745(4):469–478.
- Kinawy, M. M. 2004. Biological control of the coconut palm rhinoceros beetle (*Oryctes rhinoceros* L. Coleoptera: Scarabaeidae) using *Rhabdionvirus oryctes* Hüger in Sultanate of Oman. Egyptian Journal of Biological Pest Control 14(1):113-118.
- Kinawy, M. M., H. M. Al-Waili, and A. M. Almandhari. 2008. Review of the successful classical biological control programs in Sultanate of Oman. Egyptian Journal of Biological Pest Control 18(1):1-10.
- Kumar, S., and M. Ahmad. 2008. Impact of various methods of management of rhinoceros beetle, *Oryctes rhinoceros* Linn. in oil palm. Journal of Applied Zoological Researches 19(2):157-162.
- Laartech. 2004. Control and pest management of red palm weevil (*Rhynchophorus ferrugineus*) with bioacoustic methods.
- Lacey, L. A. 2012. Manual of techniques in invertebrate pathology. Academic Press.
- Latch, G. C. M. 1976. Studies on the susceptibility of *Oryctes rhinoceros* to some entomogenous fungi. Entomophaga 21(1):31-38.
- Latch, G. C. M., and R. E. Falloon. 1976. Studies on the use of *Metarhizium anisopliae* to control *Oryctes rhinoceros*. Entomophaga 21(1):39-48.

- Leena, S., B. T. Rayudu, and D. Muraleedharan. 2008. Insecticidal efficacy of *Chromolaena odorata* (Compositae) on the coconut beetle, *Oryctes rhinoceros* (Linn.). Entomon 33(1):41-46.
- Lever, R. J. 1969. Pests of the coconut palm. Food & Agriculture Org.
- Lin, M., Y. Han, W. Li, F. Liu, W. Xu, S. Ao, and X. Wang. 2010. Monitoring and survey on pest insects and diseases of coconut trees in Hainan. Plant Quarantine (Shanghai) 24(2):21-24.
- Lomer, C. J. 1986. Release of *Baculovirus oryctes* into *Oryctes monoceros* populations in the Seychelles. Journal of Invertebrate Pathology 47(3):237-246.
- Longworth, J. F., and G. P. Carey. 1980. The use of an indirect enzyme-linked immunosorbent assay to detect baculovirus in larvae and adults of *Oryctes rhinoceros* from Tonga. Journal of General Virology 47(2):431-438.
- Loring, D. A. 2007. Competitive testing of SPLAT-RB (*Oryctes rhinoceros*) male aggregation pheromone - mass trapping in oil palm and coconut estates. Pages 657-666 in Planter. Incorporated Society of Planters, Kuala Lumpur, Malaysia.
- Maddison, P. A., M. Beroza, and T. P. McGovern. 1973. Ethylchrysanthemumate as an attractant for the coconut rhinoceros beetle. Journal of Economic Entomology 66(3):591-592.
- Manjeri, G., R. Muhamad, and S. G. Tan. 2014. *Oryctes rhinoceros* beetles, an oil palm pest in Malaysia. Annual Review & Research in Biology 4(22).
- Mankin, R. W., D. W. Hagstrum, M. T. Smith, A. L. Roda, and M. T. K. Kairo. 2011. Perspective and promise: a century of insect acoustic detection and monitoring. American Entomologist 57(1):30-44.
- Mankin, R. W., and A. Moore. 2010. Acoustic detection of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae: Dynastinae) and *Nasutitermes luzonicus* (Isoptera: Termitidae) in palm trees in urban Guam. Journal of Economic Entomology 103(4):1135-1143.
- Mankin, R. W., A. Moore, P. R. Samson, and K. J. Chandler. 2009. Acoustic characteristics of dynastid beetle stridulations. Florida entomologist 92(1):123-133.
- Marikkar, J. M. N., and W. S. Madurapperuma. 2011. Coconut. Pages 159-177 Tropical and Subtropical Fruits: Postharvest Physiology, Processing and Packaging.
- Marschall, K. J. 1970. Introduction of a new virus disease of the coconut rhinoceros beetle in western Samoa. Pages 288-289 in.
- Marschall, K. J. 1980. Biological control of rhinoceros beetles: experiences from Samoa. Pages 658-664 in Biological control of rhinoceros beetles: experiences from Samoa.
- Marschall, K. J., and I. Ioane. 1982. The effect of re-release of *Oryctes rhinoceros* baculovirus in the biological control of rhinoceros beetles in Western Samoa. Journal of Invertebrate Pathology 39(3):267-276.
- Marshall, S. 2014. External review and personal communication for the preparation of *Oryctes rhinoceros* New Pest Response Guidelines. Personal communication to G. R. Pallipparambil on from

- Marshall, S. unpublished study, 2014. External review and personal communication for the preparation of *Oryctes rhinoceros* New Pest Response Guidelines. Personal communication to G. R. Pallipparambil on from
- Mathur, P. N., R. P. Srivastava, and A. N. Joseph. 1960. The genitalia of *Oryctes rhinoceros* L.(Coleoptera, Lamellicornia, Dynastinæ). Proceedings: Plant Sciences 51(4):181-190.
- Mini, A., and V. K. K. Prabhu. 1990. Stridulation in the coconut rhinoceros beetle *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Proceedings: Animal Sciences 99(6):447-455.
- Mohan, C., CPCRI, and ISSG. 2005. Global invasive species database: *Oryctes rhinoceros*. International Union for Conservation of Nature, Species Survival Commission, Invasive Species Specialist Group. Accessed on 10 December 2007, <http://www.issg.org/database/species/ecology.asp?si=173>.
- Mohan, K. S., and K. P. Gopinathan. 1989. Quantitation of serological cross-reactivity between two geographical isolates of *Oryctes baculovirus* by a modified ELISA. Journal of Virological Methods 24(1-2):203-213.
- Mohan, K. S., and K. P. Gopinathan. 1991. Physical mapping of the genomic DNA of the *Oryctes rhinoceros* baculovirus, KI. Gene 107(2):343-344.
- Mohan, K. S., S. P. Jayapal, and G. B. Pillai. 1983. Baculovirus disease in *Oryctes rhinoceros* population in Kerala. Journal of Plantation Crops 11(2):154-161.
- Mohan, K. S., S. P. Jayapal, and G. B. Pillai. 1985. Response of *Oryctes rhinoceros* larvae to infection by *Oryctes* baculovirus. Journal of Plantation Crops 13(2):116-124.
- Mohan, K. S., S. P. Jayapal, and G. B. Pillai. 1989. Biological suppression of coconut rhinoceros beetle *Oryctes rhinoceros* (L.) in Minicoy, Lakshadweep by *Oryctes* baculovirus - impact on pest population and damage. Journal of Plantation Crops 16:163-170.
- Mohan, K. S., and G. B. Pillai. 1983. Immuno-osmophoresis technique for quick diagnosis of *Oryctes* virus (Baculoviridae) of rhinoceros beetle *Oryctes rhinoceros* L. Indian journal of experimental biology 21(8):470-471.
- Mohan, K. S., and G. B. Pillai. 1993a. Biological control of *Oryctes rhinoceros* (L.) using an Indian isolate of *Oryctes* baculovirus. Insect Science and its Application 14(5):551-558.
- Mohan, K. S., and G. B. Pillai. 1993e. Biological control of *Oryctes rhinoceros* (L.) using an Indian isolate of *Oryctes* baculovirus. International Journal of Tropical Insect Science 14(5-6):551-558.
- Molet, T. 2014. CPHST pest datasheet: coconut rhinoceros beetle - *Oryctes rhinoceros*. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory. Updated on February 20, 2014.
- Monsarrat, P., and J. C. Veyrunes. 1976. Evidence of *Oryctes* virus in adult feces and new data for virus characterization. Journal of Invertebrate Pathology 27(3):387-389.
- Monty, J. 1974. Teratological effects of the virus Rhabdionvirus oryctes on *Oryctes rhinoceros* (L.).

- (Coleoptera, Dynastidae). Bulletin of Entomological Research 64(4):633-636.
- Monty, J. 1978. The coconut palm rhinoceros beetle, *Oryctes rhinoceros* (L.) (Col., Dynastidae) in Mauritius and its control. Revue Agricole et Sucriere de l'Île Maurice 57(2):60-76.
- Moore-Linn, C. 2009. Guam rhino beetles got rhythm. EurekAlert. Retrieved April 17, 2009, from http://www.eurekalert.org/pub_releases/2009-04/uog-grb041309.php.
- Moore, A. 2007. Assessment of the rhinoceros beetle infestation on Guam. Accessed on 2007, October 31, <http://www.guaminsects.net/CRB/docs/Moore%202007%20Assessment%20of%20the%20Rhinoceros%20Beetle%20Infestation%20on%20Guam.doc>.
- Moore, A. 2008a. Efficacy of systemic insecticide injections applied to mature coconut palms. 1-11 pp.
- Moore, A. 2008b. Preliminary bioassay of DUTREX® using adult coconut rhinoceros beetles. 1-4 pp.
- Moore, A. 2009. Temperature records from anaerobic composting experiment. Agricultural and natural resources program, University of Guam.
- Moore, A. 2011. Update on the Guam coconut rhinoceros beetle eradication project. Accessed on 21 April 2014, <http://guaminsects.net>.
- Moore, A. 2012a. Guam coconut rhinoceros beetle eradication project: Semiannual report for USDA APHIS Grant 11-8510-1123-CA (July to December, 2011). Accessed on 3 April 2014, <http://guaminsects.net>.
- Moore, A. 2012w. Technical note: using QGIS to detect georeferencing errors in an online MySQL database. Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2013a. Development of barrel traps. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2013c. Draft: Trap development experiment. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2013f. Improved pheromone traps for coconut rhinoceros beetle. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2013h. Nontarget species collected in MATT experiment. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2013i. Solar powered ultraviolet light emitting diode for CRB pheromone traps. CRB technical report series No. 29. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014a. Chicken wire vs plastic top. Research in support of the Guam coconut rhinoceros

- beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014b. CRB heat tolerance, updated on 19 February 2014. Agricultural and natural resources program, University of Guam.
- Moore, A. 2014f. External review and personal communication for the preparation of *Oryctes rhinoceros* New Pest Response Guidelines. Personal communication to G. R. Pallippambil on from
- Moore, A. 2014m. Final report for US Forest Service Grant 11-DG-11052012-101. Support for the Guam coconut rhinoceros beetle eradication project. University of Guam.
- Moore, A. 2014t. iNaturalist: Guam CRB citizen science. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014v. Minibucket escape test. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014w. Minibucket test. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014x. No rhino pamphlet. Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014z. Plastic top catch test. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A. 2014aa. Telephonic conversation about the coconut rhinoceros beetle eradication program in Guam. Personal communication to G. R. Pallippambil on 17 July 2014, from
- Moore, A., and S. Marshall. 2014. DNA analysis of Hawaii CRB. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A., and R. Quitugua. 2014a. Bird netting escape test. Research in support of the Guam coconut rhinoceros beetle eradication project. Cooperative extension service, University of Guam.
- Moore, A., and R. Quitugua. 2014b. Trifold flyer: Coconut rhinoceros beetle control tips. *in*. USDA Forest Service, USDA-APHIS, and the Guam Legislature.
- Moore, A., R. Quitugua, M. Siderhurst, and E. Jang. 2014. Improved traps for the coconut rhinoceros beetle, *Oryctes rhinoceros*. Cooperative extension service, University of Guam.
- Morin, J. P., D. Rochat, C. Malosse, M. Lettere, R. D. d. Chenon, H. Wibwo, and C. Descoins. 1996. Ethyl 4-methyloctanoate, major component of *Oryctes rhinoceros* (L.) (Coleoptera, Dynastidae) male pheromone. Comptes Rendus de l'Académie des Sciences. Série III, Sciences de la Vie 319(7):595-602.
- Muir, F., and O. H. Swezey. 1916. The cane-borer beetle in Hawaii and its control by natural enemies. Report of work of the Experiment Station of the Hawaiian Sugar Planters' Association, Honolulu, Division of Entomology bulletin 13:102.

- Muniappan, R. 2002. Pests of Coconut and Their Natural Enemies in Micronesia. *Micronesica* Supplement 6:105-110.
- Muñoz, L., M. P. Bosch, G. Rosell, and A. Guerrero. 2009. Asymmetric synthesis of (R)- and (S)-4-methyloctanoic acids. A new route to chiral fatty acids with remote stereocenters. *Tetrahedron Asymmetry* 20(4):420-424.
- Murali, G., and G. Alka. 2002. An opportunistic bacterial pathogen, *Pseudomonas alcaligenes*, may limit the perpetuation of *Oryctes* virus, a biocontrol agent of *Oryctes rhinoceros* L. *Biocontrol Science and Technology* 12(4):507-512.
- Murphy, D. J. 2007. Future prospects for oil palm in the 21st century: Biological and related challenges. *European journal of lipid science and technology* 109(4):296-306.
- Muthiah, C., and R. Bhaskaran. 2000. Screening of coconut hybrids/varieties and management of rhinoceros beetle on coconut. *Indian Coconut Journal* 31(3):58-59.
- Muthiah, C., and S. Mohan. 2002. Rhinoceros beetle management in coconut. *Indian Farming* 51(11):14-16.
- Nair, C. P., B. Sathiamma, M. Chandrika, and G. Murali. 1998. Newer approaches in the integrated pest management in coconut. *Indian Coconut Journal (Cochin)* 29(4):99-103.
- Navy Region Hawaii. 2014. Navy increases efforts to limit the spread of the coconut rhinoceros beetle on Joint Base Pearl Harbor-Hickam. Accessed on 5 May 2014
- New, T. R. 2005. ‘Inordinate fondness’: a threat to beetles in south east Asia? *Journal of Insect Conservation* 9(3):147-150.
- Nirula, K. K. 1957. Observations on the green muscardine fungus in populations of *Oryctes rhinoceros*. *Journal of Economic Entomology* 50(6).
- Nirula, K. K., J. Antony, and K. P. Menon. 1952. Investigations on the pests of the coconut palm. The rhinoceros beetle. (*Oryctes rhinoceros* L.): life history and habits. *Indian Coconut Journal* 5:57-70.
- Nirula, K. K., K. Radha, and K. P. Menon. 1955. The green muscardine disease of *Oryctes rhinoceros* L. I. Symptomatology, epi-zootiology and economic importance. *Indian Coconut Journal* 9:3-10.
- Nishida, G. M., and N. L. Evenhuis. 2000. Arthropod pests of conservation significance in the Pacific: A preliminary assessment of selected groups. *Invasive species in the Pacific: A technical review and draft regional strategy*:115.
- Norman, K., and W. Mohd Basri. 2000. Field practices for reducing the risk of rhinoceros beetle, *Oryctes rhinoceros*. Accessed on 27 May 2014, <http://www.mpob.gov.my/tot/tt95.pdf>.
- Norman, K., and W. Mohd Basri. 2004. Immigration and activity of *Oryctes rhinoceros* within a small oil palm replanting area. *Journal of Oil Palm Research* 16(2):64-77.
- Norman, K., W. Mohd Basri, M. Ramle, and A. A. Siti Ramlah. 2007. The effects of mortality and influence of pheromone trapping on the infestation of *Oryctes rhinoceros* in an oil palm

- plantation. *Journal of Asia-Pacific Entomology* 10(3):239-250.
- Oehlschlager, C. 2005. Current status of trapping palm weevils and beetles. Pages 123-143 in Planter. Incorporated Society of Planters.
- Okaraonye, C. C., and J. C. Ikewuchi. 2009. Nutritional Potential of *Oryctes rhinoceros* larva. *Pakistan Journal of Nutrition* 8(1):35-38.
- Onyeike, E. N., E. O. Ayalogu, and C. C. Okaraonye. 2005. Nutritive value of the larvae of raphia palm beetle (*Oryctes rhinoceros*) and weevil (*Rhyncophorus pheonicis*). *Journal of the Science of Food and Agriculture* 85(11):1822-1828.
- Orth, J. F. 2007. Rhino Blasty. Invasive Species Weblog. Retrieved December 7, 2007, from <http://invasivespecies.blogspot.com/2007/11/rhino-blasty.htm>.
- Pacific Islands Pest List Database. 2009. *Oryctes rhinoceros*. Suva, Fiji Islands. Accessed on 6 May 2009, <http://wwwx.spc.int:8088/pld/report?action=11&searchString=O>.
- Paco, K. 2013. Rhino beetle workshop held at UOG. Kuam news, Guam's News Network. <http://www.kuam.com>.
- Padmasheela, N. C., and M. R. Delvi. 2002. Antifeedant and mortality effects of neem oil (0.03% Azadirachtin) against III instar grubs of *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae). *Journal of Entomological Research* 26(3):239-244.
- Padmasheela, N. C., and S. Krishnan. 1996. Biochemical and histological studies on the effect of HCH and carbofuran on the enzyme activity in the grubs of *Oryctes rhinoceros* L. *Indian Journal of Environment and Toxicology* 6(1):22-25.
- Pardede, D., and C. Utomo. 1992. Efficacy of granular insecticides and naphthalene balls against *Oryctes rhinoceros* L. at Sei Pancur Estate. *Buletin Perkebunan* 23(1):57-62.
- Paul, W. D. 1985. Integrated control of palm pests in Tanzania. Possibilities of using *Oryctes* baculovirus against the rhinoceros beetle (*Oryctes monoceros* Ol.) (Coleoptera: Scarabaeidae: Dynastinae). *in Integrierte Bekämpfung von Palmenschädlingen in Tanzania. Möglichkeiten zur Verwendung des Oryctes-Baculovirus gegen den Nashornkäfer (Oryctes monoceros* Ol.) (Coleoptera: Scarabaeidae: Dynastinae). Verlag Josef Margraf, Aichtal; German Federal Republic.
- Paulose, S., and C. C. Abraham. 1997. Effect of *Baculovirus oryctes* (Kerala isolate) infection on consumption and its utilization of food by *Oryctes rhinoceros* grubs. *Indian Journal of Entomology* 59(3):311-315.
- Payne, C. C. 1974. The isolation and characterization of a virus from *Oryctes rhinoceros*. *Journal of General Virology* 25(1):105-116.
- PestID. 2014. Pest identification database. Query for *Oryctes rhinoceros* and *Oryctes* spp. Accessed, <https://mokcs14.aphis.usda.gov/aqas>.
- PestLens. 2014. First report of the coconut rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae), in Hawaii. Accessed on 6 June 2014, <https://pestlens.info>.

- Peter, A. C., and P. E. Kenmore. 2005. Impact of educating farmers about biological control in farmer field schools. United States Department of Agriculture, Forest Service, Davos, Switzerland. Accessed on 2007/12/10, <http://www.bugwood.org/arthropod2005/vol1/6a.pdf>.
- Philippine Coconut Authority. 1998a. Control the coconut rhinoceros beetle using the green muscardine fungus. Technoguide No. 4. Bago Oshiro, Davao City. Accessed on 28 April 2014, <http://www.pca.da.gov.ph>.
- Philippine Coconut Authority. 1998d. Integrated pest management for rhinoceros beetle. Technoguide No. 1. Bago Oshiro, Davao City. Accessed on 28 April 2014, <http://www.pca.da.gov.ph>.
- Philippine Coconut Authority. 2005. Green muscardine fungus, a lethal powder to control the coconut rhinoceros beetle. Technoguide No. 11. Bago Oshiro, Davao City. Accessed on 28 April 2014, <http://www.pca.da.gov.ph>.
- Pimentel, D., S. McNair, J. Janecka, J. Wightman, C. Simmonds, C. O'connell, E. Wong, L. Russel, J. Zern, and T. Aquino. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems & Environment* 84(1):1-20.
- Poinar, G. O. 1973. Description and observations on a cuticular infection of *Thelastoma pterygoton* sp. n.(Thelastomatidae: Nematoda) from *Oryctes* spp.(Scarabaeidae: Coleoptera). Pages 37-42 in Proceedings of the Helminthological Society of Washington.
- Ponnamma, K. N., N. Lalitha, and A. S. Khan. 2001. Oil palm mesocarp waste - a potential breeding medium for rhinoceros beetle, *Oryctes rhinoceros* L. *International Journal of Oil Palm Research* 2(1):37-40.
- PQR EPPO. 2013. PQR (v. 5.0)—EPPO database on quarantine pests: *Oryctes rhinoceros*. Plant Quarantine data Retrieval system, European and Mediterranean Plant Protection Organization. Accessed on 2 April 2014, <http://www.eppo.int>.
- Prasad, G. S., V. R. Bhagwat, and T. V. R. S. Sharma. 2007. Optimization of *Oryctes baculovirus* dose for efficient disease transmission in *Oryctes rhinoceros*. *Indian Journal of Plant Protection* 35(1):50-52.
- Prasad, G. S., V. Jayakumar, H. R. Ranganath, and V. R. Bhagwat. 2008a. Bio-suppression of coconut rhinoceros beetle, *Oryctes rhinoceros* L.(Coleoptera: Scarabaeidae) by *Oryctes baculovirus* (Kerala isolate) in South Andaman, India. *Crop protection* 27(6):959-964.
- Prasad, G. S., V. Jayakumar, and T. V. R. S. Sharma. 2008c. Management of coconut rhinoceros beetle (*Oryctes rhinoceros*) by augmentation of *Oryctes baculovirus* (Kerala isolate) in Little Andaman Islands. *Indian Journal of Agricultural Sciences* 78(11):962-965.
- Prior, C., and M. Arura. 1985. The infectivity of *Metarhizium anisopliae* to two insect pests of coconuts. *Journal of Invertebrate Pathology* 45(2):187-194.
- Punnuri, S. M., and B. P. Singh. 2013. Oil palm. Pages 392-414 *Biofuel crops: production, physiology and genetics*.
- Purrini, K. 1989. *Baculovirus oryctes* release into *Oryctes monoceros* population in Tanzania, with

- special reference to the interaction of virus isolates used in our laboratory infection experiments. *Journal of Invertebrate Pathology* 53(3):285-300.
- Quitugua, R. 2010. Detector dogs: coconut rhinoceros beetles (Video).
- Ragoussis, V., A. Giannikopoulos, E. Skoka, and P. Grivas. 2007. Efficient synthesis of (\pm)-4-methyloctanoic acid, aggregation pheromone of rhinoceros beetles of the genus *Oryctes* (Coleoptera: Dynastidae, Scarabaeidae). *Journal of Agricultural and Food Chemistry* 55(13):5050-5052.
- Rajamanickam, K., F. J. S. Kennedy, A. C. Lourduraj, and T. S. Raveendran. 1992. Attractants - an aid in rhinoceros beetle (*Oryctes rhinoceros* L.) management. *Indian Coconut Journal* (Cochin) 23(1):6-7.
- Rajamanickam, K., C. Natarajan, D. Packiaraj, and H. H. Khan. 2002. Efficacy of selected chemicals and botanicals against coconut rhinoceros beetle *Oryctes rhinoceros* L. in K. Sreedharan, P. K. Vinod Kumar, Jayarama, and B. M. Chulaki, ed. eds. Proceedings of the 15th Plantation Crops Symposium Placrosym XV, Mysore, India, 10-13 December, 2002. Central Coffee Research Institute, Coffee Research Station, Karnataka; India.
- Rajamannar, M., and G. Indiravathi. 2000. Detection of baculovirus infection in rhinoceros beetle (*Oryctes rhinoceros* L.) through DAC-Indirect ELISA and DIBA. *Journal of Plantation Crops* 28(2):89-93.
- Raju, D. S. 1983. A note on major pest problems of cashew, coconut and arecanut and their control in Goa. 523-529.
- Ramlah Ali, A. S., M. Ramle, W. Mohd Basri, T. Jackson, T. Glaret, and K. Norman. 2001. History and detection of *Oryctes rhinoceros* virus and microbial infection in *Oryctes rhinoceros* (L) (Coleoptera: Scarabaeidae). in Cutting-edge technologies for sustained competitiveness: Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference, Kuala Lumpur, Malaysia, 20-22 August 2001. Malaysian Palm Oil Board (MPOB), Kuala Lumpur; Malaysia.
- Ramle, M., I. Ghani, W. Mohd Basri, T. R. Glare, and T. A. Jackson. (Article). 2010. Optimization of the polymerase chain reaction (PCR) method for the detection of *Oryctes rhinoceros* virus. *Journal of Oil Palm Research* 22:736-749.
- Ramle, M., T. Glare, T. Jackson, W. Mohd Basri, K. Norwan, and A. S. Ramlah Ali. 2001. The sensitivity of polymerase chain reaction method in diagnosing the presence of *Oryctes rhinoceros* virus. in Cutting-edge technologies for sustained competitiveness: Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference, Kuala Lumpur, Malaysia, 20-22 August 2001. Malaysian Palm Oil Board (MPOB), Kuala Lumpur; Malaysia.
- Ramle, M., N. H. Hamid, W. Mohd Basri, K. Norman, and S. R. Ahmad Ali. 2005a. Mass production of *Metarhizium anisopliae* using solid fermentation and wet harvesting methods. Proceedings of the PIPOC 2005 International Palm Oil Congress (Agriculture, Biotechnology and Sustainability).
- Ramle, M., N. Kamarudin, N. H. Hamid, and R. Z. A. Cik Mohd. 2013. Delivery techniques of

- Metarhizium* for biocontrol of rhinoceros beetles in oil palm plantations. Planter 89(1049):571-583.
- Ramle, M., N. Kamarudin, and W. Mohd Basri. 2011a. Trap for the auto dissemination of *Metarhizium anisopliae* in the management of rhinoceros beetle, *Oryctes rhinoceros*. Journal of Oil Palm Research 23(1):1011-1017.
- Ramle, M., N. Kamarudin, A. Na, S. R. A. Ali, and W. Mohd Basri. 2007. Application of powder formulation of *Metarhizium anisopliae* to control *Oryctes rhinoceros* in rotting oil palm residues under leguminous cover crops. Pages 319-331 in Journal of Oil Palm Research. Malaysian Palm Oil Board (MPOB), Kuala Lumpur; Malaysia.
- Ramle, M., W. Mohd Basri, N. Kamarudin, S. R. Ahmad Ali, and N. H. Hamid. 2006. Research into the commercialization of *Metarhizium anisopliae* (Hyphomycetes) for biocontrol of oil palm rhinoceros beetle, *Oryctes rhinoceros* (Scarabaeidae), in oil palm. Journal of Oil Palm Research, Special Issue:37-49.
- Ramle, M., W. Mohd Basri, N. Kamarudin, S. Mukesh, and S. R. A. Ali. 1999. Impact of *Metarhizium anisopliae* (Deuteromycotina: Hyphomycetes) applied by wet and dry inoculum on oil palm rhinoceros beetles, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Journal of Oil Palm Research 11(2):25-40.
- Ramle, M., W. Mohd Basri, K. Norman, T. R. Glare, and T. A. Jackson. 2005b. The incidence and use of *Oryctes* virus for control of rhinoceros beetle in oil palm plantations in Malaysia. Journal of Invertebrate Pathology 89(1):85-90.
- Ramle, M., K. Norman, S. R. A. Ali, and W. Mohd Basri. 2008. *Metarhizium* granules for control of rhinoceros beetle. MPOB information series, TT No. 404.
- Ramle, M., K. Norman, I. A. Ghani, W. Mohd Basri, T. A. Jackson, C. C. Tey, and A. M. Ahdly. 2011c. Molecular approaches in the assessment of *Oryctes rhinoceros* virus for the control of rhinoceros beetle in oil palm plantations. Journal of Oil Palm Research 23:1096-1109.
- Ramle, M., K. Norman, and W. Mohd Basri. 2009. Pathogenicity of granule formulations of *Metarhizium anisopliae* against the larvae of the oil palm rhinoceros beetle, *Oryctes rhinoceros* (L.). Journal of Oil Palm Research 21:602-612.
- Ratcliffe, B. C. 2006. Scarab beetles in human culture. The Coleopterists Bulletin 60(sp5):85-101.
- Richards, N. K., T. R. Glare, I. Aloali'I, and T. A. Jackson. 1999. Primers for the detection of *Oryctes* virus from Scarabaeidae (Coleoptera). Molecular ecology 8(9):1552-1553.
- Ridgell, C. 2009. Guam continues crusade to eradicate rhino beetles. KUAM News. Pacific Telestations. 2009, February 28, <http://www.kuam.com/bm/news/guam-continues-crusade-to-eradicate-rhino-beetles.shtml?12842>.
- Roskov, Y., T. Kunze, L. Abucay, L. Paglinawan, T. Orrell, A. Culham, N. Bailly, P. Kirk, T. Bourgoin, G. Baillargeon, W. Decock, A. De Wever, and V. Didžiulis. 2014. Species 2000 & ITIS Catalogue of Life. Integrated Taxonomic Information System. Accessed on 17 March 2014, www.catalogueoflife.org.

- Rumsey, A. 2012. From discovery to eradication: the coconut rhinoceros beetle on Guam. *in.*
- Sadakathulla, S., and T. K. Ramachandran. 1990. A novel method to control rhinoceros beetle, *Oryctes rhinoceros* L. in coconut. Indian Coconut Journal (Cochin) 21(7-8):10-12.
- Sakthivel, P., P. Neelanarayanan, and C. Sivaprakasam. 2008. Utilization of aggregation pheromone for monitoring rhinoceros beetle (*Oryctes rhinoceros*) in coconut and oil palm groves. Insect Environment 14(2):78-80.
- Santos, G. A., P. A. Batugal, A. Othman, L. Baudouin, and J. P. Labouisse. 1996. Manual on Standardized Research Techniques in Coconut Breeding. IPGRI Cogent.
- Sathiamma, B., C. Mohan, and M. Gopal. 2001. Biocontrol potential and its exploitation in coconut pest management. Pages 261-283 Biocontrol Potential and its Exploitation in Sustainable Agriculture. Springer.
- Schoolmeesters, P. 2014a. Scarabs: World Scarabaeidae Database (version Aug 2013). Species 2000 & ITIS Catalogue of Life. Accessed on 17 March 2014, www.catalogueoflife.org/col.
- Schoolmeesters, P. 2014b. Scarabs: World Scarabaeidae Database (version Aug 2013). Latest taxonomic scrutiny of *Oryctes rhinoceros* in Sep 2013. Species 2000 & ITIS Catalogue of Life. Accessed on 17 March 2014, www.catalogueoflife.org/col.
- Schreiner, I. 1989. Biological control introductions in the Caroline and Marshal Islands. Proceedings of the Hawaiian Entomological Society 29:57-69.
- Secretariat of the Pacific Community. 2004. Pacific pest info No. 54 (54). Secretariat of the Pacific Community: Plant Protection Service, Private Mail Bag, Suva, Fiji Islands. Tel: (679) 3370-733; Fax: (679) 3370-021. 4 pp.
- Sharma, S., and S. G. Gupta. 1988. Rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Dynastidae) on banana from Nagaland. Bulletin of Entomology (New Delhi) 29(2):228-230.
- Sime Darby Plantation. n.d. SIME RB pheromone: An effective and environment friendly product specifically developed for mass trapping rhinoceros beetles. Sime Darby Agri-BioSdn Bhd, Selangor Darul Ehsan, Malaysia. Accessed on 28 May 2014, http://www.simedarbyplantation.com/upload/Sime_RB_Pheromone.pdf.
- Singh, A., and S. Gandhi. 2010. Agricultural insect pest: Occurrence and infestation level in agricultural fields of Vadodara, Gujarat. International Journal of Scientific and Research Publications 2(4):1-5.
- Sivakumar, T. 2001. Occurrence of *Oryctes rhinoceros* Linn. grubs in palms infested with *Rhynchophorus ferrugineus* F. Insect Environment 7(2):67-67.
- Sivakumar, T., and C. Mohan. 2013. Occurrence of rhinoceros beetle, *Oryctes rhinoceros* (L.), on banana cultivars in Kerala. Pest Management In Horticultural Ecosystems 19(1):99-101.
- Smith, M. 2014. Meet the beetles: Hawaii mobilizes to fight bug invasion. CNN. <http://www.cnn.com/2014/02/09/us/hawaii-beetle-invasion/index.html>.
- Smith, S. L., and A. Moore. 2008. Early detection and pest risk assessment: Coconut rhinoceros

- beetle. Accessed on 3 March 2014,
http://guaminsects.net/uogces/kbwiki/images/1/13/CRB_Pest_Risk_Assessment.pdf.
- Sreelatha, K. B., and P. R. Geetha. 2008. Histomorphological derangements in the ovary of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) treated with methanolic extract of *Annona squamosa* leaves. Entomon 33(2):107-112.
- Sreelatha, K. B., and P. R. Geetha. 2010. Disruption of oocyte development and vitellogenesis in *Oryctes rhinoceros* treated with methanolic extract of *Eupatorium odoratum* leaves. Journal of Biopesticides 3(1):253-258.
- Sreelatha, K. B., K. Rakhi, V. S. Aswathi, V. V. Nair, G. R. Chikku, V. Vipin, and M. Anuja. 2011. Laboratory evaluation of insecticidal activity of *Adathoda vasica* (Acanthaceae) and *Glyricidia maculata* (Leguminosae) on the third instar larvae of *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae). Journal of Biopesticides 4(2):144-149.
- Stenersen, J. 2004. Chemical pesticides: Mode of action and toxicology. CRC Press, Boca Raton, Florida. 276 pp.
- Stiling, P. 1993. Why do natural enemies fail in classical biological control programs? American Entomologist 39(1):31-37.
- Stride, G. 1977. Coconut palm rhinoceros beetle. Pages 4-4 in Advisory Leaflet, South Pacific Commission.
- Subaharan, K. 2004. Green muscardine fungus for coconut rhinoceros beetle control. Planter 80(944):717-720.
- Sudharto, P. S., R. Y. Purba, D. Rochat, and J. P. Morin. 2001. Synergy between empty oil palm fruit bunches and synthetic aggregation pheromone (ethyl 4-methyloctanoate) for mass trapping of *Oryctes rhinoceros* beetles in the oil palm plantations in Indonesia. in Cutting-edge technologies for sustained competitiveness: Proceedings of the 2001 PIPOC International Palm Oil Congress, Agriculture Conference, Kuala Lumpur, Malaysia, 20-22 August 2001. Malaysian Palm Oil Board (MPOB), Kuala Lumpur; Malaysia.
- Sujatha, A., C. P. R. K. Nair, and D. V. R. Rao. 2002. Field studies on rhinolure trap in the control of rhinoceros beetle (*Oryctes rhinoceros*) in coconut. in K. Sreedharan, P. K. Vinod Kumar, Jayarama, and B. M. Chulaki, ed. eds. Proceedings of the 15th Plantation Crops Symposium Placrosym XV, Mysore, India, 10-13 December, 2002. Central Coffee Research Institute, Coffee Research Station, Karnataka; India.
- Sujatha, A., and N. B. V. C. Rao. 2004. Natural occurrence of biological agents (*Oryctes baculovirus* and *Metarrhizium anisopliae*) of rhinoceros beetle in Andhra Pradesh. Insect Environment 10(2):69-70.
- Sullivan, M., T. Molet, and L. Jackson. 2013. Palm commodity-based survey guidelines. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Cooperative Agriculture Pest Survey. Accessed on 2013/10/28,
<http://caps.ceris.purdue.edu/survey/palm/reference/2014>.

- Surany, P. 1960. Diseases and biological control in rhinoceros beetles. Technical Papers. South Pacific Commission 128.
- Sushil, K., and A. Mukhtar. 2005. Field biology of rhinoceros beetle *Oryctes rhinoceros* L. on oil palm under South Gujarat condition. Indian Journal of Forestry 28(1):63-68.
- Swamy, C. M. K., and Puttaswamy. 2004. Longevity and efficiency of aggregation pheromones in trapping rhinoceros beetle, *Oryctes rhinoceros* (Linnaeus) (Coleoptera: Scarabaeidae). Insect Environment 10(1):23-24.
- Swapna, T. R., and P. Ahamed. 2005. Scientific rationality of ITK on pest management in coconut. Indian Coconut Journal 36(8):20-23.
- Sweeney, R. 2008. First coconut rhinoceros beetle captured in Yigo. KUAM News. Pacific Telestations. 12 July 2008, <http://www.kuam.com>.
- Tey, C. C., and C. T. Ho. 1995. Infection of *Oryctes rhinoceros* L. by application of Metarhizium anisopliae (Metsch.) Sorokin to breeding sites. Planter 71(837):563-567.
- Thai Agricultural Standard. 2008. Good Agricultural Practices for aromatic coconut. TAS 1001-2008. THAI AGRICULTURAL STANDARD. National Bureau of Agricultural Commodity and Food Standards Ministry of Agriculture and Cooperatives.
- The Plant List. 2013. Version 1.1. Published on the internet. Accessed on 26 March 2014, <http://www.theplantlist.org/>.
- TNAU. n.d. Crop protection: Coconut. Rhinoceros beetle, *Oryctes rhinoceros*. Agritech Portal. Accessed on 27 May 2014, http://agritech.tnau.ac.in/crop_protection/crop_prot_crop_insect_oil_coconut.html.
- Triplehorn, C. A., N. F. Johnson, D. J. Borror, and Elizabeth A. McMahan Endowment. 2005. Borror and DeLong's introduction to the study of insects (7th). Thompson Brooks/Cole, Belmont, CA. x, 864 p. pp.
- Uili, S. 1980. Agricultural development in Tokelau. Alafua agricultural bulletin 5(4):23-25.
- Unnikrishnan Nair, G. S. 2012. Sacred war against a sturdy beetle. Indian Coconut Journal (India).
- USDA-APHIS. 2014a. The coconut rhinoceros beetle. United States Department of Agriculture, Animal and Plant Health Inspection Service. Accessed on 3 May 2014, http://www.aphis.usda.gov/wps/portal/aphis/home?l=dm&urile=wcm%3Apath%3A/aphis_content_library/sa_our_focus/sa_plant_health/sa Domestic pests_and_diseases/sa_pests_and_diseases/sa_insects/sa_coconut_rhino_beetle.
- USDA-APHIS. 2014b. Coconut rhinoceros beetle response program on Oahu. Environmental assessment, March 2014. Accessed
- USDA-APHIS EPICA. 2007. EPICA pest notification: Coconut rhinoceros beetle, *Oryctes rhinoceros*, outbreak in American Guam. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Exotic Pest Information Collection and Analysis. Accessed, <https://www.gpdd.info/search.cfm?search=epica>.

- USDA-APHIS EPICA. 2009. EPICA pest notification: *Wodyetia bifurcata* (foxtail palm) a host of coconut rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Accessed on 1 July 2010, <https://www.gpdd.info/search.cfm?search=epica>.
- USDA-FAS. 2014. Oilseeds: world markets and trade. Accessed on 5 May 2014, <http://usda.mannlib.cornell.edu/usda/fas/oilseed-trade//2010s/2014/oilseed-trade-05-09-2014.pdf>.
- USDA-NRCS. 2014. Federal and state threatened and endangered plants. United States Department of Agriculture (USDA), Natural Resources Conservation Services. Accessed on Feb 10, 2014 from <http://plants.usda.gov/threat.html>.
- USDA. 2009. National Plant Health Emergency Management Framework. Accessed
- USDA. 2010. Emergency Response Manual. Accessed
- USDA. 2014. Current map of CRB activities. SitRep - coconut rhinoceros beetle finds Honolulu, HI. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. Accessed on 2 May 2014, <http://hdoa.hawaii.gov/pi/files/2014/01/CRB-Map3-21-14.pdf>.
- USDA, and NRCS. 2014. The PLANTS Database. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed on 26 March 2014, <http://plants.usda.gov>.
- USFWS. 2014. Endangered species database. Search for congeneric hosts of the coconut rhinoceros beetle. Accessed on 6 June 2014, <http://www.fws.gov/endangered/>.
- Vander Meer, R. K. 1987. Per cent emergent weight: a roadmap to adult rhinoceros beetle, *Oryctes rhinoceros*, behaviour. Journal of Insect Physiology 33(6):437-441.
- Vander Meer, R. K., U. R. Ghatak, S. K. Alam, and P. C. Chakraborti. 1979. (plus or minus)-Des-N-morphinan: a unique bridged hydrocarbon attractant for the rhinoceros beetle, *Oryctes rhinoceros*; and development of an olfactometer. Environmental Entomology 8(1):6-10.
- Vargo, A. 2000. Coconut Rhinoceros Beetle (*Oryctes rhinoceros*). Agricultural Pests of the Pacific. Accessed on 2000, January, http://www.ctahr.hawaii.edu/adap2/Publications/ADAP_pubs/2000-4.pdf.
- Vargo, A. M. 1995. Coconut Rhinoceros Beetle. Biological Control in the Western United States: Accomplishments and Benefits of Regional Research Project W-84, 1964-1989 3361:171.
- Varma, Y. K. 2013. Efficacy of ecofriendly management against rhinoceros beetle grubs in coconut. Journal of Biopesticides 2:101-103.
- Venkatarajappa, P. 2001. Residual toxicity of cypermethrin in the larvae of coconut pest *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). Journal of Environmental Biology 22(1):19-21.
- Vidyasagar, P., and S. K. Bhat. 1991. Pest management in coconut gardens. Journal of Plantation Crops 19(2):163-182.
- Wan Zaki, W. M., M. R. C. Salmah, A. A. Hassan, and A. Ali. 2009. Composition of various stages of *Oryctes rhinoceros* (Linn) (Coleoptera: Scarabaeidae) in mulch of oil palm empty fruit

- bunches. Planter 85(997):215-220.
- Waterhouse, D. F. 1993. The major arthropod pests and weeds of agriculture in Southeast Asia: Distribution, importance and origin. Australian Centre for International Agricultural Research.
- Wilson, T. G. 2004. The molecular site of action of juvenile hormone and juvenile hormone insecticides during metamorphosis: how these compounds kill insects. Journal of Insect Physiology 50(2):111-121.
- Wraight, S. P., and A. E. Hajek. 2009. Manipulation of arthropod pathogens for IPM. Concepts, Tactics, Strategies and Case Studies:131.
- Young, E. C. 1974. The epizootiology of two pathogens of the coconut palm rhinoceros beetle. Journal of Invertebrate Pathology 24(1):82-92.
- Young, E. C. 1975. A study of rhinoceros beetle damage in coconut palms. Pages vi + 63-vi + 63 in Technical Paper, South Pacific Commission.
- Young, E. C. 1986. The rhinoceros beetle project: history and review of the research programme. Agriculture, Ecosystems & Environment 15(2):149-166.
- Young, E. C., and J. F. Longworth. 1981. The epizootiology of the baculovirus of the coconut palm rhinoceros beetle (*Oryctes rhinoceros*) in Tonga. Journal of Invertebrate Pathology 38(3):362-369.
- Zelazny, B. 1972. Studies on *Rhabdionvirus oryctes*. I. Effect on larvae of *Oryctes rhinoceros* and inactivation of the virus. Journal of Invertebrate Pathology 20(3):235-241.
- Zelazny, B. 1973a. Studies on Rhabdionvirus oryctes. II. Effect on adults of *Oryctes rhinoceros*. Journal of Invertebrate Pathology 22(1):122-126.
- Zelazny, B. 1973e. Studies on Rhabdionvirus oryctes. III. Incidence in the *Oryctes rhinoceros* population of Western Samoa. Pages 359-363 in.
- Zelazny, B. 1975. Behaviour of young rhinoceros beetles, *Oryctes rhinoceros*. Entomologia Experimentalis et Applicata 18(2):135-140.
- Zelazny, B. 1976. Transmission of a baculovirus in populations of *Oryctes rhinoceros*. Journal of Invertebrate Pathology 27(2):221-227.
- Zelazny, B. 1977a. Occurrence of the baculovirus disease of the coconut palm rhinoceros beetle in the Philippines and in Indonesia. FAO Plant Protection Bulletin 25(2):73-77.
- Zelazny, B. 1977c. *Oryctes rhinoceros* populations and behavior influenced by a baculovirus. Journal of Invertebrate Pathology 29(2):210-215.
- Zelazny, B. 1978. Methods of inoculating and diagnosing the baculovirus disease of *Oryctes rhinoceros*. Fao (food and agriculture organization of the united nations) plant protection bulletin 26(4):163-168.
- Zelazny, B. 1979. Virulence of the baculovirus of *Oryctes rhinoceros* from ten locations in the

- Philippines and in Western Samoa. Journal of Invertebrate Pathology 33(1):106-107.
- Zelazny, B., and A. Alfiler. 1986. *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) larva abundance and mortality factors in the Philippines. Environmental Entomology 15(1):84-87.
- Zelazny, B., A. Alfiler, and A. Crawford. 1987. Preparation of a baculovirus inoculum for use by coconut farmers to control rhinoceros beetle (*Oryctes rhinoceros*). FAO Plant Protection Bulletin 35.
- Zelazny, B., and A. R. Alfiler. 1987. Ecological methods for adult populations of *Oryctes rhinoceros* (Coleoptera, Scarabaeidae). Ecological Entomology 12(2):227-238.
- Zelazny, B., and A. R. Alfiler. 1991. Ecology of baculovirus-infected and healthy adults of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) on coconut palms in the Philippines. Ecological Entomology 16(2):253-259.
- Zelazny, B., A. R. Alfiler, and A. Lolong. 1989. Possibility of resistance to a baculovirus in populations of the coconut rhinoceros beetle (*Oryctes rhinoceros*). Fao (food and agriculture organization of the united nations) plant protection bulletin 37(2):77-82.
- Zelazny, B., A. Lolong, and A. M. Crawford. 1990. Introduction and field comparison of baculovirus strains against *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) in the Maldives. Environmental Entomology 19(4):1115-1121.
- Zelazny, B., and A. C. Neville. 1972. Endocuticle layer formation controlled by non-circadian clocks in beetles. Journal of Insect Physiology 18(10):1967-1979.
- Zhang, H., and T. A. Jackson. 2008. Autochthonous bacterial flora indicated by PCR-DGGE of 16S rRNA gene fragments from the alimentary tract of *Costelytra zealandica* (Coleoptera: Scarabaeidae). Journal of applied microbiology 105(5):1277-1285.
- Zhong, B., LüChaoJun, D. Wang, H. Li, and W. Qin. 2012. Effects of methanol extracts of *Mikania micrantha* on the growth and development of the rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Dynastidae). Acta Entomologica Sinica 55(9):1062-1068.
- Zhong, B., LüChaoJun, D. Wang, W. Qin, H. Li, and Z. Wang. 2013. Biological and morphological observations on *Oryctes rhinoceros* (Coleoptera: Dynastidae) in the laboratory. Acta Entomologica Sinica 56(2):167-172.
- Zimmermann, G. 1982. Effect of high temperatures and artificial sunlight on the viability of conidia of *Metarhizium anisopliae*. Journal of Invertebrate Pathology 40(1):36-40.
- Zimmermann, G. 1993. The entomopathogenic fungus *Metarhizium anisopliae* and its potential as a biocontrol agent. Pesticide Science 37(4):375-379.
- Zimmermann, G. 2007. Review on safety of the entomopathogenic fungus *Metarhizium anisopliae*. Biocontrol Science and Technology 17(9):879-920.

How to Use the Guidelines

Use *New Pest Response Guidelines: Oryctes rhinoceros* (L.) when designing a program to detect, monitor, control, contain or eradicate an outbreak of this pest in the United States and collaborating territories.

The United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (USDA–APHIS–PPQ) developed the guidelines through discussion, consultation or agreement with staff members at the USDA-Agricultural Research Service and advisors at universities.

Any new detection may require the establishment of an incident command system to facilitate emergency management. This document is meant to provide the information necessary to launch a response to a *O. rhinoceros* detection.

If *O. rhinoceros* is detected, a site-specific action plan will be based on the guidelines. As the program develops and new information becomes available, the guidelines will be updated.

Users

The guidelines are intended as a field reference for the following users who have been assigned responsibilities for a plant health emergency involving *O. rhinoceros*:

- ◆ PPQ personnel
- ◆ Emergency response coordinators
- ◆ State agriculture department personnel
- ◆ Others concerned with developing local survey or control programs

Contacts

When an emergency program for *O. rhinoceros* has been implemented, the success of the program depends on the cooperation, assistance and understanding of other involved groups. The appropriate liaison and information officers should distribute news of the program's progress and developments to interested groups including the following:

- ◆ Academic entities with agricultural interests
 - ◆ Agricultural interests in other countries
 - ◆ Commercial interests
 - ◆ Grower groups such as specific commodity or industry groups
 - ◆ Land-grant universities and cooperative extension services
 - ◆ National, state and local news media
 - ◆ Other federal, state, county and municipal agricultural officials
 - ◆ Public health agencies
 - ◆ The public
 - ◆ State and local law enforcement officials
 - ◆ Tribal governments
-

Initiating an Emergency Pest Response Program

An emergency pest response program consists of detection and delimitation and may be followed by programs in regulation, containment, eradication and control. The New Pest Advisory Group (NPAG) will evaluate the pest. After assessing the risk to U.S. plant health and consulting with experts and regulatory personnel, NPAG will recommend a course of action to PPQ management.

Follow this sequence when initiating an emergency pest response program:

1. A new or reintroduced pest is discovered and reported
2. The pest is examined and pre-identified by regional or area identifier
3. The pest's identity is confirmed by a national taxonomic authority recognized by the USDA–APHIS–PPQ National Identification System

4. Published New Pest Response Guidelines are consulted or a new NPAG is assembled to evaluate the pest
5. Depending on the urgency, official notifications are made to the National Plant Board, cooperators and trading partners
6. A delimiting survey is conducted at the site of detection
7. An incident assessment team may be sent to evaluate the site
8. A recommendation is made, based on the assessment of surveys, other data and recommendation of the incident assessment team or the NPAG as follows:
 - A. Take no action
 - B. Regulate the pest
 - C. Contain the pest
 - D. Suppress the pest
 - E. Eradicate the pest
9. State departments of agriculture are consulted
10. If appropriate, a control strategy is selected
11. A PPQ Deputy Administrator authorizes a response
12. A command post is selected and the incident command system is implemented
13. State departments of agriculture cooperate with parallel actions using a unified command structure
14. Trace-back and trace-forward investigations are conducted
15. Field identification procedures are standardized
16. Data reporting is standardized
17. Regulatory actions are taken
18. Environmental assessments are completed as necessary
19. Treatment is applied for required pest generational time
20. Environmental monitoring surveys are conducted to evaluate program success
21. Pest monitoring surveys are conducted to evaluate program success
22. Programs are designed for eradication, containment or long-term use

Preventing an Infestation

Federal and state regulatory officials must conduct inspections and apply prescribed measures to ensure that pests do not spread within or between properties.

Scope

The guidelines are divided into the following chapters:

1. *Introduction* on page 1-1
2. *Taxonomy* on page 2-1
3. *Identification* on page 3-1
4. *Biology* on page 4-1
5. *Damage* on page 5-1
6. *Pathways* on page 5-1
7. *Survey Procedures* on page 7-1
8. *Control Procedures* on page 8-1
9. *Regulatory Procedures* on page 9-1

The guidelines also include appendices and a list of literature cited.

Authorities

The regulatory authority for taking the actions listed in the guidelines is contained in the following authorities:

- ◆ Plant Protection Act of 2000 (Statute 7 USC 7701-7758)
 - ◆ Executive Order 13175, Consultation and Coordination with Indian and Tribal Governments
 - ◆ Fish and Wildlife Coordination Act
 - ◆ National Historic Preservation Act of 1966
 - ◆ Endangered Species Act
 - ◆ Endangered and Threatened Plants (50 CFR 17.12)
 - ◆ National Environmental Policy Act
-

Program Safety

The safety of the public and program personnel is a priority in pre-program planning and training and throughout program operations. Safety officers and supervisors must enforce on-the-job safety procedures.

Support for Program Decision Making

The USDA–APHIS–PPQ–Center for Plant Health, Science and Technology (CPHST) provides technical support to emergency pest response program directors concerning risk assessments, survey methods, control strategies, regulatory treatments and other aspects of the pest response programs. PPQ managers consult with state departments of agriculture in developing guidelines and policies for pest response programs.

How to Obtain the Guidelines

The guidelines are a portable electronic document that is updated periodically. Download the current version from its source and then use Adobe Reader® to view it on your computer screen. You can print the guidelines for convenience; however, links and navigational tools are only functional when the document is viewed in Adobe Reader®. Remember that printed copies of the guidelines are obsolete once a new version has been issued.

Conventions

Conventions are established by custom and are widely recognized and accepted. Conventions used in the guidelines are listed in this section.

Advisories

Advisories are used throughout the guidelines to bring important information to your attention. Please carefully review each advisory. The definitions have been updated to coincide with the American National Standards Institute (ANSI) and are formatted as follows:

Example

Example provides an example of the topic.

Important

Important indicates information that is helpful.

CAUTION

CAUTION indicates that people could possibly be endangered and slightly hurt.

DANGER

DANGEROUS indicates that people could easily be hurt or killed.

NOTICE

NOTICE indicates a possibly dangerous situation where goods might be damaged.

⚠ WARNING

WARNING indicates that people could possibly be hurt or killed.

Boldfacing

Boldfaced type is used to highlight negative or important words. These words are **never, not, do not, other than** and **prohibited**.

Lists

Bulleted lists indicate information listed in no particular order. Numbered lists indicate that information will be used in a particular order.

Disclaimers

All disclaimers are located on the page that follows the cover.

Control Data

Information placed at the top and bottom of each page helps users keep track of where they are in the guidelines. At the top of the page is the chapter. At the bottom of the page is the year, edition, title and page number. PPQ–Pest Detection and Emergency Programs (PDEP) is the unit responsible for the content of the guidelines.

Decision Tables

Decision tables are used throughout the guidelines. The first and middle columns in each table represent conditions, and the last column represents the action to take after considering all conditions listed for that row. Begin with the column headings and move left-to-right. If the condition does not apply, then continue one row at a time until you find the condition that does apply.

Table A-1 How to use decision tables

If you:	And if the condition applies:	Then:
read this column cell and row first	continue in this cell	TAKE the action listed in this cell
find the previous condition does not apply, then read this column cell	continue in this cell	TAKE the action listed in this cell

Footnotes

When space allows, figure and table footnotes are located directly below the

associated figure or table. However, for multi-page tables or tables that cover the length of a page, footnote numbers and footnote text cannot be listed on the same page. If a table or figure continues beyond one page, the associated footnotes will appear on the page following the end of the figure or table.

Heading Levels

Within each chapter and section there can be four heading levels; each heading is green and is located within the middle and right side of the page. The first-level heading is indicated by a horizontal line across the page with the heading following directly below. The second-, third- and fourth-level headings each have a font size smaller than the preceding heading level. The fourth-level heading runs in with the text that follows.

Hypertext Links

Figures and tables are cross-referenced in the body of the guidelines and are highlighted in blue hypertext type.

Italics

The following items are italicized throughout the guidelines:

- ◆ Cross-references to headings and titles
- ◆ Names of publications
- ◆ Scientific names

Numbering Scheme

A two-level numbering scheme is used in the guidelines for pages, tables and figures. The first number represents the chapter. The second number represents the page, table or figure. This numbering scheme allows for identification and updating. Dashes are used in the page numbering to differentiate page numbers from decimal points.

Transmittal Number

The transmittal number contains the month, year and a consecutively issued number (beginning with -01 for the first edition and increasing consecutively for each update to the edition). The transmittal number is only changed when the specific chapter sections, appendices, tables or index is updated. If no changes are made, then the transmittal number remains the unchanged. The transmittal number only changes when a new guidelines edition is issued or changes are made to the entire guidelines.

Acknowledgements

Writers, editors, reviewers, creators of cover images and other contributors to the guidelines are acknowledged in the acknowledgements section. Names, affiliations and Website addresses of the creators of photographic images, illustrations and diagrams are acknowledged in the caption accompanying the figure.

How to Cite the Guidelines

Cite the guidelines as follows:

U.S. Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine. 2014. New Pest Response Guidelines: *Oryctes rhinoceros* (L.) Coleoptera Scarabaeidae, Coconut Rhinoceros Beetle. Washington, D.C.: Government Printing Office.

http://www.aphis.usda.gov/import_export/plants/manuals/online_manuals.shtml

How to Find More Information

Contact USDA–APHIS–PPQ–PDEP–Emergency Management for more information regarding the guidelines. Refer to *Resources* on page B-1 for contact information.

Resources

Use *Appendix B Resources* to find the Website addresses, street addresses and telephone numbers for the resources mentioned in the guidelines.

- ◆ [Center for Plant Health, Science and Technology \(USDA–APHIS–PPQ–CPHST\)](#)
- ◆ [Pest Detection and Emergency Programs, Emergency Management \(USDA–APHIS–PPQ–PDEP–EM\)](#)
- ◆ [PPQ Treatment Manual](#)
- ◆ [Plant, Organism and Soil Permits \(APHIS–PPQ\)](#)
- ◆ [National Program Manager for Native American Program Delivery and Tribal Liaison \(USDA–APHIS–PPQ\)](#)

14082 S. Poston Place
Tucson, AZ 85736
Telephone: (520) 822-5440
- ◆ [Biological Control Coordinator \(USDA–APHIS–CPHST\)](#)
- ◆ FIFRA Coordinator (USDA-APHIS-PPQ-PDEP)
4700 River Road
Riverdale, MD 20737
Telephone: (301) 851-2243
- ◆ [Environmental Compliance Coordinator \(USDA–APHIS–PPQ–PDEP\)](#)
4700 River Road
Riverdale, MD 20737
Telephone: (301) 851-2345

- ◆ [PPQ Forms](#)
- ◆ [List of State Plant Health Directors \(SPHD\)](#)
- ◆ [List of State Plant Regulatory Officials \(SPRO\)](#)
- ◆ [National Climatic Center, Database Administration](#)
Box 34
Federal Building
151 Patton Ave
Asheville, NC 28801-5001
- ◆ [CAPS Survey Manual](#)
- ◆ [GenBank®](#)
- ◆ [iPhyClassifier](#)

Forms

PPQ Form 391, Specimens for Determination C-2

PPQ Form 523, Emergency Action Notification C-6

PPQ Form 305, Insect Collection Worksheet for Genotype Analysis C-8

PPQ Form 391, Specimens for Determination

<p>This report is authorized by law (7 U.S.C. 147a). While you are not required to respond, your cooperation is needed to make an accurate record of plant pest conditions.</p>			<p>FORM APPROVED OMB NO. 0579-0010 See reverse for additional OMB information.</p>																																																											
<p>U.S. DEPARTMENT OF AGRICULTURE ANIMAL AND PLANT HEALTH INSPECTION SERVICE</p> <p>SPECIMENS FOR DETERMINATION</p>			<p>Instructions: Type or print information requested. Press hard and print legibly when handwritten. Item 1 - assign number for each collection beginning with year, followed by collector's initials and collector's number. Example (collector, John J. Dingle): 83-JJD-001. Pest Data Section - Complete Items 14, 15 and 16 or 19 or 20 and 21 as applicable. Complete Items 17 and 18 if a trap was used.</p>																																																											
<p>1. COLLECTION NUMBER</p>			2. DATE	3. SUBMITTING AGENCY																																																										
			MO DA YR	<input type="checkbox"/> State Cooperator <input type="checkbox"/> PPQ <input type="checkbox"/> Other _____																																																										
SENDER AND ORIGIN	<p>4. NAME OF SENDER</p> <p>6. ADDRESS OF SENDER</p> <p>ZIP</p>			5. TYPE OF PROPERTY (Farm, Feedmill, Nursery, etc.)																																																										
				7. NAME AND ADDRESS OF PROPERTY OR OWNER																																																										
				COUNTRY/COUNTY																																																										
PURPOSE	<p>8. REASON FOR IDENTIFICATION ("X" ALL Applicable Items)</p> <table> <tr> <td>A. <input type="checkbox"/> Biological Control (Target Pest Name)</td> <td>E. <input type="checkbox"/> Livestock, Domestic Animal Pest</td> </tr> <tr> <td>B. <input type="checkbox"/> Damaging Crops/Plants</td> <td>F. <input type="checkbox"/> Possible Immigrant (Explain in REMARKS)</td> </tr> <tr> <td>C. <input type="checkbox"/> Suspected Pest of Regulatory Concern (Explain in REMARKS)</td> <td>G. <input type="checkbox"/> Survey (Explain in REMARKS)</td> </tr> <tr> <td>D. <input type="checkbox"/> Stored Product Pest</td> <td>H. <input type="checkbox"/> Other (Explain in REMARKS)</td> </tr> </table> <p>9. IF PROMPT OR URGENT IDENTIFICATION IS REQUESTED, PLEASE PROVIDE A BRIEF EXPLANATION UNDER "REMARKS".</p>					A. <input type="checkbox"/> Biological Control (Target Pest Name)	E. <input type="checkbox"/> Livestock, Domestic Animal Pest	B. <input type="checkbox"/> Damaging Crops/Plants	F. <input type="checkbox"/> Possible Immigrant (Explain in REMARKS)	C. <input type="checkbox"/> Suspected Pest of Regulatory Concern (Explain in REMARKS)	G. <input type="checkbox"/> Survey (Explain in REMARKS)	D. <input type="checkbox"/> Stored Product Pest	H. <input type="checkbox"/> Other (Explain in REMARKS)																																																	
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<p>19. PLANT PATHOLOGY - PLANT SYMPTOMS ("X" one and describe symptoms)</p> <table> <tr> <td><input type="checkbox"/> ISOLATED</td> <td><input type="checkbox"/> GENERAL</td> </tr> </table>		<input type="checkbox"/> ISOLATED	<input type="checkbox"/> GENERAL																																																											
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<p>23. TENTATIVE DETERMINATION</p>																																																														
<p>24. DETERMINATION AND NOTES (Not for Field Use)</p>						<p>FOR IIBIII USE DATE RECEIVED</p> <p>NO. LABEL SORTED PREPARED DATE ACCEPTED</p> <p>RR</p>																																																								
<p>PPQ FORM 391 Previous editions are obsolete. (AUG 02)</p>																																																														
<p>This is a 6-Part form. Copies must be disseminated as follows:</p> <table> <tr> <td><input type="checkbox"/> PART 1 - PPQ</td> <td><input type="checkbox"/> PART 2 - RETURN TO SUBMITTER AFTER IDENTIFICATION</td> <td><input type="checkbox"/> PART 3 - IIBIII OR FINAL IDENTIFIER</td> </tr> <tr> <td><input type="checkbox"/> PART 4 - INTERMEDIATE IDENTIFIER</td> <td><input type="checkbox"/> PART 5 - INTERMEDIATE IDENTIFIER</td> <td><input type="checkbox"/> PART 6 - RETAINED BY SUBMITTER</td> </tr> </table>						<input type="checkbox"/> PART 1 - PPQ	<input type="checkbox"/> PART 2 - RETURN TO SUBMITTER AFTER IDENTIFICATION	<input type="checkbox"/> PART 3 - IIBIII OR FINAL IDENTIFIER	<input type="checkbox"/> PART 4 - INTERMEDIATE IDENTIFIER	<input type="checkbox"/> PART 5 - INTERMEDIATE IDENTIFIER	<input type="checkbox"/> PART 6 - RETAINED BY SUBMITTER																																																			
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Figure C-1 Example of PPQ Form 391, Specimens for Determination, side 1

PPQ Form 391, Specimens for Determination (cont.)

OMB Information

According to the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number. The valid OMB control number for this information collection is 0579-0010. The time required to complete this information collection is estimated to average .25 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

Instructions

Use PPQ Form 391, Specimens for Determination, for domestic collections (warehouse inspections, local and individual collecting, special survey programs, export certification).

BLOCK	INSTRUCTIONS
1	<p>1. Assign a number for each collection beginning the year, followed by the collector's initials and collector's number</p> <p>EXAMPLE In 2001, Brian K. Long collected his first specimen for determination of the year. His first collection number is 01-BLK-001</p> <p>2. Enter the collection number</p>
2	Enter date
3	Check block to indicate Agency submitting specimens for identification
4	Enter name of sender
5	Enter type of property specimen obtained from (farm, nursery, feedmill, etc.)
6	Enter address
7	Enter name and address of property owner
8A-8L	Check all appropriate blocks
9	Leave Blank
10	Enter scientific name of host, if possible
11	Enter quantity of host and plants affected
12	Check block to indicate distribution of plant
13	Check appropriate blocks to indicate plant parts affected
14	Check block to indicate pest distribution
15	<ul style="list-style-type: none"> • Check appropriate block to indicate type of specimen • Enter number specimens submitted under appropriate column
16	Enter sampling method
17	Enter type of trap and lure
18	Enter trap number
19	Enter X in block to indicate isolated or general plant symptoms
20	Enter X in appropriate block for weed density
21	Enter X in appropriate block for weed growth stage
22	Provide a brief explanation if Prompt or URGENT identification is requested
23	Enter a tentative determination if you made one
24	Leave blank

Distribution of PPQ Form 391

Distribute PPQ Form 391 as follows:

1. Send Original along with the sample to your Area Identifier.
2. Retain and file a copy for your records.

Figure C-2 Example of PPQ Form 391, Specimens for Determination, side 2

Purpose

Submit PPQ Form 391, Specimens for Determination, along with specimens for positive or negative identification.

Instructions

Follow the instructions in on page [C-3](#). Inspectors must provide all relevant collection information with samples. This information should be shared within both the state and the regional office program contact. If a sample tracking database is available at the time of detection, please enter the collection information in the system as quickly as possible.

Distribution

Distribute PPQ Form 391 as follows:

1. Send the original with the sample to your area identifier.
2. Keep and file a copy for your records.

Table C-1 Instructions for completing PPQ Form 391, Specimens for Determination

Block	Description	Instructions
1	COLLECTION NUMBER	1. ASSIGN a collection number for each collection as follows: 2-letter state code-5-digit sample number (survey identification number in parentheses); example: PA-1234 (0402010001) 2. CONTINUE consecutive numbering for each subsequent collection 3. ENTER the collection number
2	DATE	ENTER the date of the collection
3	SUBMITTING AGENCY	PLACE an X in the PPQ block
4	NAME OF SENDER	ENTER the sender's or collector's name
5	TYPE OF PROPERTY	ENTER the type of property from which the specimen was collected (farm, feed mill, nursery, etc.)
6	ADDRESS OF SENDER	ENTER the sender's or collector's address
7	NAME AND ADDRESS OF PROPERTY OR OWNER	ENTER the name and address of the property from which the specimen was collected
8A-8H	REASONS FOR IDENTIFICATION	PLACE an X in the correct block
9	IF PROMPT OR URGENT IDENTIFICATION IS REQUESTED, PLEASE GIVE A BRIEF EXPLANATION UNDER "REMARKS"	LEAVE BLANK; ENTER remarks in Block 22
10	HOST INFORMATION, NAME OF HOST	If known, ENTER the scientific name of the host
11	QUANTITY OF HOST	If applicable, ENTER the number of acres planted with the host
12	PLANT DISTRIBUTION	PLACE an X in the applicable box
13	PLANT PARTS AFFECTED	PLACE an X in the applicable box
14	PEST DISTRIBUTION: FEW/COMMON/ABUNDANT/EXTREME	PLACE an X in the appropriate block
15	INSECTS/NEMATODES/MOLLUSKS	PLACE an X in the applicable box to indicate type of specimen
	NUMBER SUBMITTED	ENTER the number of specimens submitted as ALIVE or DEAD under the appropriate stage
16	SAMPLING METHOD	ENTER the type of sample
17	TYPE OF TRAP AND LURE	ENTER the type of sample
18	TRAP NUMBER	ENTER the sample numbers
19	PLANT PATHOLOGY-PLANT SYMPTOMS	If applicable, check the appropriate box; otherwise LEAVE BLANK
20	WEED DENSITY	If applicable, check the appropriate box; otherwise LEAVE BLANK
21	WEED GROWTH STAGE	If applicable, check the appropriate box; otherwise LEAVE BLANK
22	REMARKS	ENTER the name of the office or diagnostic laboratory forwarding the sample; include a contact name, email address, phone number of the contact and the date forwarded to the state diagnostic laboratory or USDA-APHIS-NIS
23	TENTATIVE DETERMINATION	ENTER the preliminary diagnosis
24	DETERMINATION AND NOTES (Not for field use)	LEAVE BLANK; to be completed by the official identifier

PPQ 523 Emergency Action Notification

According to the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number. The valid OMB control number for this information is 0579-0102. The time required to complete this information collection is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

FORM APPROVED - OMB NO. 0579-0102

U.S. DEPARTMENT OF AGRICULTURE ANIMAL AND PLANT HEALTH INSPECTION SERVICE PLANT PROTECTION AND QUARANTINE		SERIAL NO.
EMERGENCY ACTION NOTIFICATION		
3. NAME AND QUANTITY OF ARTICLE(S)		1. PPQ LOCATION 2. DATE ISSUED
		4. LOCATION OF ARTICLES
		5. DESTINATION OF ARTICLES
6. SHIPPER		7. NAME OF CARRIER
		8. SHIPMENT ID NO.(S)
9. OWNER/CONSIGNEE OF ARTICLES		10. PORT OF LADING 11. DATE OF ARRIVAL
Name: _____		12. ID OF PEST(S), NOXIOUS WEEDS, OR ARTICLE(S)
Address: _____ _____ _____		12a. PEST ID NO. 12b. DATE INTERCEPTED
PHONE NO. _____ FAX NO. _____		13. COUNTRY OF ORIGIN 14. GROWER NO.
SS NO. _____ TAX ID NO. _____		15. FOREIGN CERTIFICATE NO.
		15a. PLACE ISSUED 15b. DATE
<p>Under Sections 411, 412, and 414 of the Plant Protection Act (7 USC 7711, 7712, and 7714) and Sections 10404 through 10407 of the Animal Health Protection Act (7 USC 8303 through 8306), you are hereby notified, as owner or agent of the owner of said carrier, premises, and/or articles, to apply remedial measures for the pest(s), noxious weeds, and/or article(s) specified in Item 12, in a manner satisfactory to and under the supervision of an Agriculture Officer. Remedial measures shall be in accordance with the action specified in Item 16 and shall be completed within the time specified in Item 17.</p> <p>AFTER RECEIPT OF THIS NOTIFICATION, ARTICLES AND/OR CARRIERS HEREIN DESIGNATED MUST NOT BE MOVED EXCEPT AS DIRECTED BY AN AGRICULTURE OFFICER. THE LOCAL OFFICER MAY BE CONTACTED AT:</p>		
16. ACTION REQUIRED		
<input type="checkbox"/> TREATMENT: _____ <input type="checkbox"/> RE-EXPORTATION: _____ <input type="checkbox"/> DESTRUCTION: _____ <input type="checkbox"/> OTHER: _____		
<p>Should the owner or owner's agent fail to comply with this order within the time specified below, USDA is authorized to recover from the owner or agent cost of any care, handling, application of remedial measures, disposal, or other action incurred in connection with the remedial action, destruction, or removal.</p>		
17. AFTER RECEIPT OF THIS NOTIFICATION COMPLETE SPECIFIED ACTION WITHIN (Specify No. Hours or No. Days):		18. SIGNATURE OF OFFICER:
ACKNOWLEDGMENT OF RECEIPT OF EMERGENCY ACTION NOTIFICATION <i>I hereby acknowledge receipt of the foregoing notification.</i>		
SIGNATURE AND TITLE:		DATE AND TIME:
19. REVOCATION OF NOTIFICATION		
ACTION TAKEN:		
SIGNATURE OF OFFICER:		DATE:

PPQ FORM 523 (JULY 2002) Previous editions are obsolete.

Figure C-3 Example of PPQ 523 Emergency Action Notification

Purpose

Issue a PPQ 523 Emergency Action Notification (EAN) to hold all host plant material at facilities that house the suspected plant material directly or indirectly connected to positive confirmations. Once an investigation determines that the plant material is not infested or testing determines there is no risk, the material may be released and the release documented on the EAN.

The EAN may also be issued to hold plant material in fields pending positive identification of suspect samples. When a decision is made to destroy plants, or in the case of submitted samples, once positive confirmation is received, the same EAN that placed plants on hold also documents any actions taken, such as destruction and disinfestation. More action may be warranted if other fields test positive for this pest.

Instructions

If plant lots or shipments are held as separate units, issue separate EANs for each unit of suspected and associated plant material. The EANs are issued under the authority of the Plant Protection Act of 2000 (state 7 USC 7701-7758). States are advised to issue their own hold orders parallel to the EAN to prevent intrastate movement of plant material.

When using an EAN to hold articles, the EAN language must clearly specify actions to be taken. An EAN issued for positive testing and positive associated plant material must clearly state that the material must be disposed of, or destroyed, and the areas disinfested. Include language that these actions will occur at the owner's expense and will be supervised by a regulatory official. If the EAN is used to issue a hold order for further investigations and testing of potentially infested material, use the same EAN to document any disposal, destruction and disinfestation orders resulting from the investigations or testing.

PPQ Form 305, Insect Collection Worksheet for Genotype Analysis

According to the Paperwork Reduction Act of 1995, an agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a valid OMB control number. The valid OMB control number for this information collection is 0579-0104. The time required to complete this information collection is estimated to average .17 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information.

OMB APPROVED
0579-0104
EXP: XX/XXXX

UNITED STATES DEPARTMENT OF AGRICULTURE ANIMAL AND PLANT HEALTH INSPECTION SERVICE PLANT PROTECTION AND QUARANTINE		1. INSECT NAME	
INSECT COLLECTION WORKSHEET FOR GENEOTYPE ANALYSIS			
COMPLETE FOR EACH TRAP CONTAINING SPECIMENS			
2. SUBMITTER'S NAME		3. SUBMITTER'S ADDRESS (Include ZIP Code)	
4. SUBMITTER'S EMAIL ADDRESS			
5. SUBMITTING AGENCY		TELEPHONE NUMBER FAX NUMBER	
<input type="checkbox"/> STATE <input type="checkbox"/> USDA <input type="checkbox"/> OTHER ORGANIZATION			
TRAP DATA			
6. DATE COLLECTED	7. DATE OF LAST TRAP CHECK	8. TRAP NUMBER	9. NEAREST PORT OF ENTRY (Including Military Bases)
10. TRAP TYPE		<input type="checkbox"/> Delta <input type="checkbox"/> Milk Carton <input type="checkbox"/> Light Trap <input type="checkbox"/> Other _____	
11. TRAP LOCATION Address		12. APPROXIMATE NUMBER OF SPECIMENS IN TRAP	
Town or City (or nearest one)	State		
County	ZIP code		
Longitude (if available)	Latitude (if available)	Other Coordinates	
14. SPECIAL TREATMENTS OF SPECIMENS (e.g., freezing conditions, use of alcohol, prolonged storage conditions, host if no trap used, etc.)			
15. SEND TO MOLECULAR DIAGNOSTICS USDA, APHIS, PPQ OTIS CPHST LABORATORY 1398 WEST TRUCK ROAD BUZZARDS BAY, MA 02542		Telephone Number: 508-563-0900 Fax Number: 508-563-0903	16. DATE SENT
FOR LABORATORY USE ONLY			
DATE RECEIVED	OTIS ID NUMBER		
PPQ FORM 305 AUG 2014	Previous edition is obsolete.		

Figure C-4 Example of PPQ 305, Insect Collection Worksheet for Genotype Analysis

Taxonomic Support for Surveys

Background

The National Identification Services (NIS) coordinates the identification of plant pests in support of the USDA's regulatory programs. Accurate and timely identifications are the foundation of quarantine action decisions and are essential in the effort to safeguard the nation's agricultural and natural resources.

The NIS employs and collaborates with scientists who specialize in various plant pest groups, including weeds, insects, mites, mollusks and plant diseases. These scientists are stationed at a variety of institutions around the country, including federal research laboratories, plant inspection stations, land-grant universities and natural history museums. Additionally, the NIS Molecular Diagnostics Laboratory is responsible for providing biochemical testing to support the agency's pest monitoring programs.

On 13 June 2007, the PPQ Deputy Administrator issued PPQ Policy No. PPQ-DA-2007-02, which established the role of PPQ NIS as the point of contact for all domestically detected confirmations and communications regarding introduced plant pests. The position of Domestic Diagnostics Coordinator (DDS) was established to administer the policy and coordinate domestic diagnostics for the NIS. Any questions regarding sample routing or communication of results can be directed to the PPQ Survey Field Operations Manager (Brian Kopper: phone (919) 855-7318; e-mail, brian.j.kopper@aphis.usda.gov) or the Domestic Diagnostics Coordinator

Taxonomic Support and Survey Activity

Taxonomic support for pest surveillance is fundamental to conducting quality surveys. A misidentification or incorrectly screened target pest can yield a missed opportunity for early detection when control strategies are more viable and cost effective. The importance of good sorting, screening and identification during domestic survey activity cannot be overemphasized.

Fortunately most states have, or have access to, good taxonomic support. Taxonomic support should be considered in cooperative agreements as another cost of conducting surveys. Taxonomists and laboratories within the state often

require supplies, develop training materials or hire technicians to meet their screening and identification needs. When considering whether to survey for a particular pest during a given year, consider the challenges of taxonomic support.

Sorting and Screening

For survey activities, the proper sorting and screening of samples prior to examination by an identifier will result in improved turn-around times for identification.

Sorting

Sorting is the first level of activity to ensure samples submitted are of the correct target group for the pests being surveyed. Select those plant samples that are symptomatic if appropriate. A minimum level of sorting is expected of surveyors depending on the target group, training, experience or demonstrated ability.

Screening

Screening involves a higher level of sample discrimination such that the suspect target pests are separated from the known non-target or native species of similar taxa. For example, only the suspect target species or those that appear similar to the target species are forwarded to an identifier for confirmation. This process can involve a first and second level of screening depending on the difficulty and complexity of the group. Again, the appropriate degree of screening depends on the target group, training, experience and demonstrated ability of the screener.

Check individual survey protocols to determine if samples should be sorted, screened or sent in their entirety (raw) before submitting for identification. If not specified in the protocol, assume that samples should be sorted to some degree.

Resources for Sorting, Screening and Identification

Sorting, screening and identification resources and aids useful to CAPS and PPQ surveys are best developed by taxonomists knowledgeable in the taxa that include the target pests and the established or native organisms in the same group that are likely in the samples and can be confused with the target. These aids are often regionally based and can be in the form of dichotomous keys, picture guides or reference collections. The NIS encourages the development of these resources, and when aids are complete, posts them in the CAPS Website for the benefit of others. Please see the following Website for some available screening aids:
<https://caps.ceris.purdue.edu/node/34>.

Other Entities for Taxonomic Assistance in Surveys

When taxonomic support within a state is inadequate for a particular survey, other entities may assist including PPQ identifiers, universities and state departments of agriculture from other states and independent institutions. Check with the PPQ regional CAPS coordinators regarding the availability of taxonomic assistance.

Universities and State Departments of Agriculture

Depending on the taxonomic group, a few cases involve two entities that are interested in receiving samples from other states. Arrangements for payment, if required for these taxonomic services, can be made through cooperative agreements. The National Plant Diagnostic Network (NPDN) also has several regional hub laboratories that can provide service identifications of plant pests in their respective regions. PPQ currently has arrangements with two state departments of agriculture (Oregon and Washington) and one university (Mississippi State University) through Farm Bill funding to provide taxonomic services to other states should they desire it. Contact your CAPS NOM for more information.

Independent Institutions

The Raleigh PPQ Field Operations office has set up multi-state arrangements for the Carnegie Museum of Natural History to identify insects from trap samples. They prefer to receive unscreened material and work on a fee basis per sample.

PPQ Port Identifiers

There are over 70 identifiers in PPQ that are stationed at ports of entry to primarily identify pests encountered in international commerce including conveyances, imported cargo, passenger baggage and propagative material. In some cases, these identifiers process survey samples generated during PPQ-conducted surveys and occasionally those from CAPS surveys. They can also enter the PPQ form 391 for a suspect CAPS target or other suspect new pests into our PestID database prior to their being forwarded for confirmation by an NIS-recognized authority. The list of PPQ port identifiers and their areas of coverage can be found on the following Website:

http://inside.aphis.usda.gov/ppq/php/manual/mac/identifiers_co-lat_natl_spec.pdf

PPQ Domestic Identifiers

PPQ has a limited number of domestic identifiers normally stationed at universities who are primarily responsible for survey samples. Domestic

identifiers can handle unscreened or partially screened samples with prior arrangement through the PPQ CAPS NOM. They can also act as an intermediary alternative to sending an unknown suspect to, for example, the ARS Systematic Entomology Lab (SEL) depending on their specialty and area of coverage. In addition, these identifiers can enter the PPQ form 391 for a suspect CAPS target or other suspect new pests into our PestID database prior to forwarding the sample for confirmation by an NIS-recognized authority.

Bobby Brown
 Domestic Entomology Identifier
 USDA–APHIS–PPQ
 901 W. State Street
 Smith Hall, Purdue University
 West Lafayette, IN 47907-2089
 Phone: (765) 496-9673
 Fax: (765) 494-0420
 e-mail: robert.c.brown@aphis.usda.gov

Specialty: Forest pests
 (Coleoptera, Hymenoptera)

Area of coverage: Primarily northeast and Midwest U.S.

Julieta Brambila
 Domestic Entomology Identifier
 USDA–APHIS–PPQ
 P.O. Box 147100
 Gainesville, FL 32614-7100
 Phone: (352) 395-4792
 e-mail: julieta.brambila@aphis.usda.gov

Specialty: Adult Lepidoptera,
 Heteroptera

Area of coverage: Primarily eastern U.S.

Kira Metz
 Domestic Entomology Identifier
 USDA–APHIS–PPQ
 Minnie Belle Heep 216D
 2475 TAMU
 College Station, TX 77843
 Phone: (979) 450-5492
 e-mail: kira.zhaurova@aphis.usda.gov

Specialty: Lepidoptera,
 Coleoptera

Area of coverage: Primarily western/southern U.S.

ATTENTION SAMPLE SUBMITTERS: When sending domestic samples to domestic identifiers, you must notify them first by e-mail or phone that you plan to send samples, describing what type and how many. Once notification has been sent, forward an e-mail to them with a tracking number for the express carrier through whom the samples were forwarded. If you plan to send a domestic sample to a national specialist, notify the Coordinated Agricultural Project National Operations Manager (CAPS NOM) or the National Domestic Diagnostics Coordinator prior to sending the sample.

Final Confirmations

If identifiers or laboratories at the state, university or institution level suspect the detection of a CAPS target, a plant pest new to the United States or a quarantine pest of limited distribution in a new state, the specimens should be forwarded to an NIS-recognized taxonomic authority for final confirmation. State cooperators and university taxonomists can go through a PPQ area identifier or the appropriate domestic identifier that covers their area to place the specimen into the PPQ system. They will then send the specimen to the NIS-recognized authority for that taxonomic group. In some cases, domestic identifiers can make final confirmation depending on their ID authority, accreditation and proficiency testing.

State-level taxonomists, who are reasonably certain that they have a new United States record, CAPS target or federal quarantine pest, can send the specimen directly to the NIS-recognized authority, but must notify their State Survey Coordinator (SSC), PPQ Pest Survey Specialist (PSS), State Plant Health Director (SPHD) and State Plant Regulatory Official (SPRO).

Before forwarding these suspect specimens to identifiers or to the NIS-recognized authority for confirmation, please complete a PPQ form 391 with the tentative determination. In addition, fax a copy of the completed PPQ Form 391 to ‘Attention: Domestic Diagnostics Coordinator’ at (301) 851-2115, or send a PDF file in an e-mail to aphis-ppq.nis.urgents@aphis.usda.gov with the overnight carrier tracking number.

The addresses of the NIS-recognized authorities to which suspect specimens are to be sent can be found at the following Website:

http://inside.aphis.usda.gov/ppq/php/manual/mac/identifiers_co-lat_natl_spec.pdf

Only use the ‘Urgent’ listings for suspected new United States or state records of a significant pest, and the ‘Prompt’ listings for all others.

When the specimen is forwarded to a specialist for final confirmation, use an overnight carrier, insure proper and secure packaging and include a hard copy of the PPQ form 391 marked ‘Urgent’ or ‘Prompt’ as previously described.

Please contact the National Operations Manager assigned to this new pest response by calling (919) 855-7335.

Digital Images for Confirmation of Domestic Detections

For the aforementioned confirmations, send specimens, not digital images. For entry into the National Agricultural Pest Information System (NAPIS), digital

imaging confirmations can be used for new county records of widespread pests by state taxonomists or identifiers with their prior approval. These scientists always have the prerogative to request that the specimens be sent. Pests with PPQ regulatory programs may require specimens to be sent to SEL for new county records depending on the species.

Communication of Results

If no suspect CAPS target, program pests or new detections are found, communication of these identification results can be sent by the domestic identifiers or taxonomists at other institutions directly back to the submitter. The information can be presented in a spreadsheet, in a hardcopy of PPQ form 391 or other informal means labelled with the species or ‘no CAPS target or new suspect pest species found.’ Good record keeping by the intermediate taxonomists performing these identifications is essential.

All confirmations received from the NIS-recognized authorities, positive or negative, are communicated by the NIS to the PPQ Pest Detection and Emergency Programs (PDEP) staff at PPQ headquarters. The PDEP then notifies the appropriate PPQ program managers and the SPHD and SPRO simultaneously. One of these contacts should forward the results to the originating laboratory, diagnostician, identifier and/or submitter of the specimen or sample.

Data Entry in NAPIS

For survey data entered into NAPIS, new country and state records should be confirmed by an NIS-recognized authority, while for others that are more widespread, use the identifications from PPQ identifiers or state taxonomists. When in doubt, contact the PPQ Domestic Survey Coordinator.

Sample Submission

Taxonomic support for insect surveys requires that samples be competently and consistently sorted, stored, screened (in most cases) and submitted to the identifier.

Sorting Trap Samples

When a trap is serviced, sorting is critical. Debris and non-target insect orders must be sorted from the trap material. The taxonomic level of sorting will depend on the expertise available and can be confirmed with the identifier. Adult *O. rhinoceros* specimens from the traps can easily be identified and sorted. Refer to the *Adult* in the *Identification* chapter on page 3-4.

Screening Trap Samples

Screening is a process of eliminating non-target families, genera or ‘look-a-likes’ of the surveyed species. Consult the [CAPS website](#) for screening aids for particular groups. When in doubt, however, forward the specimens to the identifier/taxonomist. The use of these aids should be coupled with training from identifiers and/or experienced screeners prior to their use.

Storage

Where appropriate, samples may be stored indefinitely in alcohol. However, samples of dried insects, such as those in sticky traps, may decompose over time if not maintained in a cool location such as a refrigerator or freezer. If insect samples have decomposed, do not submit them for identification.

Samples for Genotype Analysis

Samples collected for genotype analysis should be taken from traps every two weeks or more frequently if high humidity or high temperatures threaten the quality of specimen DNA. Collected specimens should be placed in containers

that promote drying, such as paper bags or cardboard boxes, and maintained in a cool dry place until stored in a freezer or shipped. Samples that are not immediately shipped for analysis should be stored frozen and dry.

Packaging and Shipping

Ensure specimens are dead prior to shipping by either placing them in a vial of alcohol or placing dry specimens in the freezer for at least 1 day. The following are a few tips on sorting, packaging and shipping liquids and dry samples:

Liquids

Factors such as arthropod group, life stage and the method of collection determine how the specimens are handled, preserved and shipped to the identifier. In general, mites, insect larvae, soft- and hard-bodied adult insects can be transferred to vials of 75–90% ethanol (EtOH) or an equivalent such as isopropyl alcohol. At times, Lindgren funnel trap samples containing bark beetles may also contain rainwater. To prevent later decay, drain off all liquid and replace with alcohol.

Vials should contain samples from a single trap and a printed or hand-written label with the associated collection number that can be found in the top right corner of form 391. Please use a writing utensil that is not alcohol soluble such as a Micron® pen or a pencil. Samples from multiple traps **must not** be combined in a single vial to preserve the locality-associated data. Vials can be returned to field personnel upon request.

If the mail or freight forwarder takes issue with sending specimens in alcohol, the majority of the liquid can be decanted from the vial, which should then be sealed tightly in the container immediately prior to shipping. Notify the identifier that the vials will require the alcohol be replaced as soon as they are received. If shipped quickly, the specimens should not dry out if the vial is properly sealed.

Dry Specimens

Some collection methods produce dry material that is **fragile** (**Note:** bark beetle/wood borer samples collected in Lindgren funnel traps should not be sent dry. Follow the guidelines listed in the specific protocol described in *Liquids*). Dry samples can be shipped in vials or glassine envelopes. As with the alcohol samples, make sure the collection label is associated with the sample at all times. This method is typically used for larger insects, but has a greater risk of breakage during shipping. Additionally, dry samples are often covered with debris and sometimes difficult to identify.

Ensure that samples are adequately packed to ensure safe transit to the identifier.

If a soft envelope is used, it should be wrapped in shipping bubble sheets; if a rigid cardboard box is used, samples should be packed so that movement within the container is restricted. Please include the accompanying documentation and notify the identifier prior to shipping. Remember to inform the identifier that samples are on the way, providing the approximate number and your contact information.

Samples for Genotype Analysis

When submitting insect samples for genotype analysis, include a copy of PPQ [PPQ Form 305, Insect Collection Worksheet for Genotype Analysis](#) with each sample in the shipping container.

For insects caught in traps, place the loose specimens from each trap in a paper bag with moisture-absorbing paper towels or tissue. Label the bag with the trap ID and seal with tape or staples.

Documentation

Each trap sample/vial should be documented in and accompanied by its own completed PPQ form 319, *Specimens for Determination*. You should maintain a partially pre-filled electronic copy of this form on your computer with your address and other information to save time. Indicate the name of the person making any tentative identification prior to sending to an identifier. Please ensure all applicable fields are completed and that the bottom field (block 24, *Determination and Notes*) is left blank for completion by the identifier. Include the phone number and/or e-mail address of the submitter. Other documentation in the form of notes, images, etc. can be included if useful to the determination. A method for cross-referencing the sample/vial with the accompanying form is critical. For example, write the collection number on both Form 391 and the envelope containing the sample.

Environmental Compliance

Overview

Program managers of federal emergency response or domestic pest control programs must ensure that their programs comply with all federal acts and executive orders pertaining to the environment as applicable. Two primary federal acts, the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA), often require the development of significant documentation before program actions may begin.

Program managers should also seek guidance and advice as needed from Environmental and Risk Analysis Services (ERAS), a unit of APHIS' Policy and Program Development (PPD) staff. ERAS is available to provide guidance to program managers and prepare drafts of applicable environmental documentation.

In preparing draft NEPA documentation, ERAS may also perform and incorporate assessments that pertain to other acts and executive orders described below as part of the NEPA process. The Environmental Compliance Team (ECT), a part of PPQ's Emergency Domestic Programs (EDP), will assess ERAS in the development of documents and will implement any environmental monitoring.

Leaders of the programs are strongly advised to meet with ERA and/or ECT early in the development of a program to conduct a preliminary review of applicable environmental statutes as requested by program managers or as suggested to address concerns over controversial activities. Monitoring may be conducted with regards to worker exposure, pesticide quality assurance and control, off-site chemical deposition or program efficacy. Different tools and techniques are used depending on the monitoring goals and control techniques used in the program. Staff from the ECT will work with the program manager to develop an environmental monitoring plan, conduct training to carry out the plan, provide day-to-day guidance on monitoring and provide an interpretive report of monitoring activities.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires all federal agencies to examine whether their actions may significantly affect the quality of the human environment. The purpose of NEPA is to inform the decision maker before taking action and to tell the public of the decision. Actions that are excluded from this examination, that normally require an environmental assessment and environmental impact statements, are codified in APHIS' NEPA implementing procedures located in 7 CFR 372.5.

The three types of NEPA documentation are categorical exclusions, environmental assessments and environmental impact statements.

Categorical Exclusion

Categorical exclusions (CEs) are classes of actions that do not significantly affect the quality of the human environment and for which neither an environmental assessment (EA) nor an environmental impact statement (EIS) is required. Generally, the means through which adverse environmental impacts may be avoided or minimized have been built into the actions themselves (7CFR 372.5(c)).

Environmental Assessment

An environmental assessment (EA) is a public document that succinctly presents information and analysis for the decision maker of the proposed action. An EA can lead to the preparation of an environmental impact statement, a finding of no significant impact (FONSI), or the abandonment of a proposed action.

Environmental Impact Statement

If a major federal action may significantly affect the quality of the human environment (adverse or beneficial) or the proposed action may result in public controversy, then prepare an environmental impact statement (EIS).

Endangered Species Act

The Endangered Species Act (ESA) is a statute requiring that programs consider their potential effects on federally protected species. The ESA requires programs to identify protected species and their habitats in or near program areas and to document how adverse effects to these species will be avoided. The documentation may require review and approval by the U.S. Fish and Wildlife

Service and the National Marine Fisheries Service before program activities can begin. Knowingly violating this law can lead to criminal charges against individual staff members and program managers.

Migratory Bird Treaty Act

The statute requires that programs avoid harm to over 800 endemic bird species, eggs and their nests. In some cases, permits may be available to capture birds, which require coordination with the U.S. Fish and Wildlife Service.

Clean Water Act

The statute requires various permits for work in wetlands and for potential discharge of program chemicals into water, which may require coordination with the Environmental Protection Agency, individual states and the Army Corps of Engineers. Such permits would be needed even if the pesticide label allows for direct application to water.

Tribal Consultation

The executive order requires formal government-to-government communication and interaction if a program might have substantial direct effects on any federally recognized Indian Nation. This process is often incorrectly included as part of the NEPA process, but must be completed before public involvement under NEPA. Staff should be cognizant of the conflict that could arise when proposed federal actions intersect with tribal sovereignty. Tribal consultation is designed to identify and avoid such potential conflict.

National Historic Preservation Act

The statute requires that programs consider potential impacts on historic properties (such as buildings and archaeological sites) and requires coordination with local state historic preservation offices. Documentation under this act involves preparing an inventory of the project area for historic properties and determining what effects, if any, the project may have on historic properties. This process may need public involvement and comment before the start of program activities.

Coastal Zone Management Act

The statute requires coordination with states in which programs may impact coastal zone management plans. Federal activities that may affect coastal resources are evaluated through a process called federal consistency. This process affords the public, local governments, tribes and state agencies an opportunity to review the federal action. The federal consistency process is administered individually by states with coastal zone management plans.

Environmental Justice

The executive order requires consideration of program impacts on minority and economically disadvantaged populations. Compliance is usually achieved within the NEPA documentation for a project. Programs are required to consider if the actions might impact minority or economically disadvantaged populations and if so, how such impact will be avoided.

Protection of Children

The executive order requires federal agencies to identify, assess and address environmental health and safety risks that may affect children. If such a risk is identified, measures must be described and carried out to minimize such risks.

Glossary

Definitions, Terms and Abbreviations

abiotic. pertaining to the absence of life; diseases not caused by living organisms

acute. pointed or triangular

adventitious roots. roots that arise from an atypical place, from a stem rather than as branches of a root

AFLP. Amplified Fragment Length Polymorphism; technique that uses [PCR](#) to amplify genomic DNA, cleaved by restriction enzymes to generate DNA fingerprints; a combination of RFLP and arbitrary primer PCR and does not require prior sequence knowledge

amplicon. Piece of DNA synthesized using amplification techniques such as [PCR](#)

APA. American Phytopathological Society

aperture. mouth or principal opening of the shell through which the body of the gastropod passes out of the shell

apex. tip of the spire of a snail shell at the opposite end from the aperture

APHIS. USDA–Animal and Plant Health Inspection Service

appressed. pressed close to or lying flat

approved landfill. state-licensed municipal or private landfill managed under state regulation to prevent leaching of potential pollutants into groundwater

AQAS. Agricultural Quarantine Activity System, a web database accessible from any USDA–APHIS computer

aerial treatment. application of insecticide to a treatment area via aircraft

array. arrangement of traps within one square mile

array sequence. layout of traps ([array](#)) from the core area outward to the perimeter

[\(buffer area\)](#)

ARS. USDA–Agricultural Research Service

attract and kill. IPM technique in which both pheromones and insecticides are applied to the upper canopy of an orchard, attracting male insects to the orchard where they are killed by the insecticide

augmentation. intentional addition of natural enemies via mass release in areas in which these enemies are absent, occur too late in the season or pest life cycle or are present in ineffective numbers

barrier. natural or artificial obstacle to movement

biological control. development and use of natural means of control through parasites, predators, pathogens and biological tactics to suppress a pest population density below a level that would not occur in their absence, either for a given period or permanently

biological tactics. use of any natural or derived product or technique utilizing biological applications such as gene transfer, genetic manipulation, pheromone attractants, host substitution or other biological means to suppress a pest population density below a level that would not occur in their absence, either for a given period or permanently

biometric survey. survey succeeding the delimiting survey in which properties are number and letter coded for survey purposes on a rotational basis

blacklight trap. trap with a special bulb radiating ultraviolet lights that can attract insects

blastokinesis. movement of the developing embryo into the yolks of insect eggs

block. units (e.g., 1 square mile) of a detection survey in which all survey activities are conducted

brachyblasts. short lateral branch

breeding attack. attack by an insect on a host plant to successfully breed

buffer area. survey area that is beyond the core block

bullate. appearing puckered as if blistered

calling. emission of sex pheromones by a female to attract mates

callow. condition of the adult shortly after eclosion when its cuticle is not fully sclerotized or fully mature in color

cambium. meristematic tissue in woody plants that exists between the wood ([xylem](#)) and the inner most bark ([phloem](#))

CAPS. Cooperative Agricultural Pest Survey program, partnership between all 50 states and the USDA to detect and monitor exotic pests of economic impact

cast needles. premature drop of needles from a tree

catenulate. arranged in a series of rings or chains

CFR. Code of Federal Regulations

chemical integration. direct application of selected chemicals on the host that are nontoxic or relatively nontoxic to selected parasites or predators

chimeric. composed of parts of different origin

chlorosis. yellowing of normally green tissue due to chlorophyll destruction as a result of pest damage

classical biological control. introduction of exotic natural enemies from the region of origin to provide a permanent, self-sustaining suppression of a pest population density below a level that would not occur in their absence

clavate. resembling a club, becoming increasingly wide from the base to the distal end

cold treatment. exposure of a host product to cold temperatures lethal to a target pest; may be used alone or with fumigants

commercial production area. area in which host material is grown for sale

confirmation detection. positive identification of a submitted specimen

containment. application of phytosanitary measures in and around an infested area to prevent spread of a pest

control. application of phytosanitary measures in and around an infested area to prevent spread of a pest

conterminous. having a boundary in common

core area. area of 1 square mile surrounding a confirmed detection

corm. solid swollen underground bulb-shaped stem or stem base that serves as a reproductive structure

cotyledons. embryonic leaf in seed-bearing plants

CPB. United States Department of Homeland Security–Customs and Border Protection

CPHST. PPQ–Center for Plant Health Science and Technology

crepuscular. active during twilight hours

cross transect survey. survey designed to detect the infestation in the shortest time possible; strung out along the two lines of an axis and run through the most likely host areas; the survey may eventually be replaced by one based on a grid system for improved coverage

crown. portion of a plant, typically at ground level, at which the stem and roots merge

cultural control. intentional use of simple practices or mechanical measures that may be available to control a pest population

day degree. measure of physiological time using the accumulation of heat units (degrees) above an insect's developmental threshold for a 24-hour period

d.b.h. diameter at breast height

delimiting survey. survey conducted in a susceptible area not known to be infested with the target pest

delta trap. five-sided insect trap, configured with three lateral sides arranged triangularly, equipped with a lure (*i.e.*, pheromone), a baffled edge and an adhesive surface inside to capture and secure attracted insects

dendroid. resembling a tree in form with a branching structure

denticulate. having a fine-toothed margin

destructive sampling. method of observing signs and symptoms of the presence or absence of a pest by destruction of the living sample unit; for example, removal of bark to look for larvae

detection. collection of any life stage of the target pest

detection survey. survey conducted in an environmentally favorable area in which the pest is not known to occur

developmental thresholds. minimum and/or maximum temperatures that support physiological development of a species

DHS. United States Department of Homeland Security

dieback. death of branches on woody plants, shrubs or trees; typically young shoots, twigs and distal portions of branches dies progressively toward older plant parts

disposal. method used to eliminate infested plant material or associated materials, usually at an approved landfill

diurnal. active during the day

EAN. Emergency Action Notification

eclosion. molting and escape of the adult insect from the cuticle/cocoon of the pupa, or, from the final immature instar

EDP. PPQ—Emergency and Domestic Programs

elicitins. small cysteine-rich lipid-binding proteins

ELISA. Enzyme-Linked Immunosorbent Assay, a molecular diagnostic technique

ellipsoid. surface whose plane sections are all ellipses or circles

EM. PPQ—Emergency Management

endophytes. endosymbiont, often a bacterium or fungus, that lives within a plant for at least part of its life without causing apparent disease

entomopathogen. pathogen that induces illness in insects

EPA. United States Environmental Protection Agency

epicenter. original location/point of infestation

epicormic shoots. new shoots arising near the base of the plant

epistoma. oral margin or sclerite directly behind the labrum

EPPO. European and Mediterranean Plant Protection Organization

eradication. application of phytosanitary measures to eliminate a pest from an area before it becomes too large in area or number for current technology

exotic species. pest species not native to or historically resident in North America

exudate. liquid excreted or discharged from injured plant tissues

fascicles. dense cluster or bundle

FIFRA. Federal Insecticide, Fungicide and Rodenticide Act

FONSI. Finding Of No Significant Impact

fructification. fruit bearing

fumigation. application of an approved fumigant as a treatment

funicle. part of the flagellum of the antenna proximal to the club

- fusiform.** spindle shaped; tapering at each end
- generation.** period during which a pest completes all stages of development predicted using biological information
- geniculate.** bent at a sharp angle
- girdle.** to circle and cut through a stem or the bark and outer few rings of wood, disrupting the phloem and xylem
- GIS.** geographic information systems; a computer system capable of capturing, storing, analyzing and displaying geographically referenced information
- globose.** ball shaped
- ground spray.** using ground spray equipment to apply pesticide to the ground, selected resting places, or host vegetation in a target infested area
- hastiseta.** larval body hair in which the shaft is constricted at regular intervals; apex consists of a barbed head; barbed hairs are found in pairs of tufts, borne on certain abdominal segments
- haustoria.** specialized branch of a parasite formed inside host cells to absorb nutrients
- heteroecious.** parasite that develops different stages of the life cycle on different host species
- hibernaculum.** larval overwintering refuge constructed with silk
- host.** plant that provides nutrients and is suitable for the survival and development of a pest species; a true host supports reproduction of the pest species
- host collecting.** collection and retention of infested host material for the purposes of determining characteristics of a pest's use of the host; also known as holding
- hot-zone survey.** choosing an area, typically residential, on which to concentrate surveys based on known pathway information with ZIP code-based demographic information or other scientific information; also known as a targeted survey or demographic survey
- hyaline.** transparent or nearly so; translucent; often used in the sense of colorless
- hyphae.** single, tubular filament of a fungal thallus or mycelium; the basic structural unit of a fungus
- ICS.** Incident Command System
- identification authority.** authority to confirm the presence of a particular pest contractible issued by the APHIS–National Identification Services to diagnosticians that

have demonstrated proficiency in identification

incineration. burning of plant hosts and associated soil or media resulting in their complete destruction

infection. establishment of a parasite on or within a host plant

infestation. collection of one or more target pests from an area/host

infested area. area surrounding a single detection site or a group of sites; the standard designated area of 2.5 square miles is used, unless biotic or abiotic factors dictate adjustment of this area

inoculative augmentation. flooding a chosen area with large numbers of one or more natural enemies at the time a pest occurs or is expected to occur in an area with the intention of having established populations of these natural enemies through subsequent generations for pest control

inundative augmentation. flooding a chosen area with large numbers of one or more natural enemies to exert rapid control of a pest in the present generation to prevent or decrease possible damaging host losses

intercalary. inserted between

ISIS. Integrated Survey Information System

isozyme. enzymes that differ in amino acid sequence but catalyze the same chemical reaction

labrum. upper lip abutting the clypeus in front of the mouth

limoniform. shaped like a lemon

management. application of selected phytosanitary measures in and around an infested area to keep an invading population in check when other means of population eradication would fail

maturation feeding. feeding required by an individual organism before it can successfully reproduce

mesonotum. notum of mesothorax

mesothorax. second or middle thoracic segment bearing the middle legs and the forewings

migratory species. species in which individuals habitually move from place to place especially in search of mates or egg-laying sites

MOA. Mode Of Action

monitoring survey. survey conducted at a site at which a pest was detected and an eradication program is being performed; also known as an *evaluation survey*

monophagous. pest species that feeds on only one host plant species

mycelium. mass of hyphae constituting the body (thallus) of a fungus

NAPIS. National Agricultural Pest Information System

NASS. National Agricultural Statistics Service

natural enemies. living organisms found in a natural community that kill, weaken or inhibit the biological potential of a pest species

necrosis. death or discoloration of plant tissue

NEPA. National Environmental Policy Act

NIS. PPQ—National Identification Service

nocturnal. active at night

non-migratory. species in which the individuals typically do not move far from the area of their birth

non-native. immigrant

NPAG. PPQ—New Pest Advisory Group

NPRG. New Pest Response Guidelines

obpyriform. resembling a pear and ;attached at the narrower end

oogonia. female gametangium of oomycetes, containing one or more gametes

oospore. thick-walled, sexually derived resting spore of oomycetes

parasite. organism living on the host at one or multiple life stages that may kill or debilitate the host

parasite/predator conservation. conservation of natural enemies through integrated procedures using highly selective predator/parasite friendly insecticides or techniques, biological insecticides or cultural practices favoring parasites/predators

parasitoid. organism that lives on a host (often an immature stage) when immature, but are free-living as adults; parasitoids always kill the host; like parasites, these organisms are typically host specific, and some are obligate on certain hosts, effectively finding

hosts even when host populations are small

parthenogenesis. development of an unfertilized egg into an adult female; asexual reproduction; occurs in many different invertebrates

PASS. Potentially Actionable Suspect Sample; a presumptive positive sample diagnosed or identified by provisionally approved laboratory or diagnostician with identification authority that would require confirmatory testing by an official APHIS laboratory due to the nature of the plant sampled and the necessity for federal confirmation

pathogen. infectious agent that causes disease to its host

pathway. means by which exotic plant pests are introduced in the US

PCR. Polymerase Chain Reaction, a laboratory technique that amplifies DNA sequences; useful tool for molecular identification of a pest species

PCR primers. short fragments of single-stranded DNA (15–30 nucleotides long), complementary to DNA sequences that flank the target region of interest; necessary components for the polymerase chain reaction

peduncle. stalk of an inflorescence or a stalk bearing a solitary flower in a one-flowered inflorescence

PERAL. Plant Epidemiology and Risk Analysis Laboratory

pest. insects, weeds, plant disease agents and microorganisms

PestID. database containing all the information recorded from the PPQ form 309 Pest Interception Record

phenology. study of periodic recurrent biological events of the organism

phloem. tissue that conducts synthesized food substances (*e.g.*, from leaves) to parts needed; consists primarily of sieve tubes

phyllody. development of leaf-like growths in place of normal flower parts

PIB. polyisobutylene

pitch tube. tubular mass of resin mixed with bark, wood borings and insect excrement that forms on the surface of the bark at beetle entrance holes

plant hardiness zones. zones defined in the USDA Plant Hardiness Zone Map that determine the plant species likely to thrive at a particular location; the maps are based on the mean annual minimum winter temperature divided into 10 °F zones.

pleomorphic. capable of assuming different shapes

polyphagus. organism that feeds on a wide range of plant host species

positive point. site at which the target pest species was detected

PPQ. APHIS–Plant Protection and Quarantine

predator. organism that consumes substantial numbers of prey

pronotum. upper and dorsal part of the prothorax

prosternum. sternum of the prothorax

prothorax. first thoracic ring or segment bearing the anterior legs, but no wings

protuberance. something that protrudes such as a bulge, knob or swelling

pyriform. pear shaped

regulated area. area that extends to a given distance in any direction from the epicenter of an infestation

regulated articles. all known/suspected hosts or substrates of a confirmed infestation of an exotic pest species

regulatory inspection. visual examination of host material, containers and transport

reniform. kidney shaped

rhizosphere. microenvironment in the soil, immediate around the plant root

riparian. relating to or located on the banks of a river or stream

sanitation. destruction or removal of infested plants or plant parts; decontamination of tools, equipment, containers, work space, hands, etc.

saprophyte. organism that obtains nourishment from non-living organic matter

satellite site. potentially infested property that is beyond a given distance from the confirmed infestation site

sclerite. hardened plate of the body wall bounded by membrane or sutures

sclerotization. hardening of the cuticle involving the development of crosslinks between protein chains

SEL. USDA–ARS–Systematic Entomology Laboratory

septate. with cross walls; having septa

seta (plural setae). sclerotized hair-like projection of cuticula arising from a single

trichogen cell and surrounded at the base by a small cuticular ring

sex pheromone. semiochemical secreted by an insect to attract or advertise reproductive competence to the opposite sex of the same species; these pheromones can be artificially produced and embedded in lures to trap the opposite sex

sinuate. curved or curving in and out

SL. soluble concentrate

soil treatment. application of an approved pesticide to the soil of nursery stock or within the drip line of host plants

SPHD. State Plant Health Director

SPRO. State Plant Regulatory Official

steam sterilization. use of live steam as a treatment on selected regulated items

stellate. arranged in rays or radii

sternum. entire ventral division of any segment

stunting. overall reduction in plant height due to shortening of internodes

subglobose. nearly globose

suppression. application of phytosanitary measures in an infected area to reduce pest populations

sweep net. survey method in which a mesh net suspended around a hoop is swept through the air or around vegetation to collect insects

symbiotic. mutually beneficial association of two different organisms

symptom. external and internal reactions or alterations of a plant as the result of pest feeding

teleomorph. sexual form of a fungus

TESS. Threatened and Endangered Species System

tergum. upper or dorsal surface of an insect body segment, whether consisting of one or more sclerites

thorax. middle body segment between the head and abdomen of an insect; consists of three segments ([prothorax](#), [mesothorax](#) and metathorax) each of which typically bears a pair of articulated legs

trace-back. to investigate the origin of infested plants through intermediate steps in commercial distribution channels to the origin

trace-forward. to investigate the potential distribution of infected plants from a source through steps in commercial distribution channels

trap survey. determining the occurrence and/or density of a pest species using traps placed in a predetermined pattern and serviced on a given schedule

true host. host capable of sustaining reproduction

tuberculate. covered with tubercles (wart-like projections)

TWG. Technical Working Group

tyloses. bladder-like outgrowth from certain cells in woody tissue that extends into and blocks adjacent conducting [xylem](#) cells

umbriate. shingle-like; having regularly arranged overlapping edges as in roof tiles

uninucleate. cell having one nucleus

univoltine. one generation per year

USDA. United States Department of Agriculture

USFWS. United States Fish and Wildlife Service

vacuole. generally spherical organelle within a plant cell bound by a membrane and containing dissolved materials such as metabolic precursors, storage materials or waste products

vector. carrier (*e.g.*, insect) of an infectious agent (*e.g.*, plant virus) capable of transmitting infection from one host plant to another

virescence. development of green color in place of normal flower color

visual survey. examining plant hosts, substrates or hiding places for eggs, larvae, pupae, adults of a pest or visible characteristic damage on the host by the pest

white resin streaks. viscous secretion from the plant as a result of pest attack

wing trap. disposable adhesive-coated capture devise used primarily for surveying moths

witches broom. abnormal excessive proliferation of axillary shoots resulting in a broom-like growth

xylem. woody part of plants; the supporting and water-conducting tissue consisting primarily of tracheids and vessels

zonate. marked with zones or bands; belted; striped

zonobiome. ecosystem with the same average temperature and the same volume of rainfall