Actions Toward Containment, Control, and Eradication of Invasive Conehead Termites (Blattodea: Isoptera: Termitidae)

Barbara L. Thorne,1,3,* Sue Alspach,2 Katherine E. Tenn,2 and Marah S. Clark2

1Department of Entomology, University of Maryland, College Park, MD 20742, USA, 2Florida Department of Agriculture and Consumer Services, 3125 Conner Boulevard, Tallahassee, FL 32399, USA, and 3Corresponding author, e-mail: bthorne@umd.edu

Abstract

Early, strategic IPM actions can eradicate relatively new invasive conehead termite [Nasutitermes corniger (Motschulsky) (Blattodea: Isoptera: Termitidae)] populations, preventing negative economic and ecological consequences should this pest of agriculture, structures, and natural areas become permanently established and spread. Conspicuous foraging tunnels and above-ground nests are key aspects of N. corniger biology that render colonies vulnerable to discovery and elimination. Because the goal is eradication, the termites must be controlled wherever found—structure, yard, park, overgrown lot, orchard, forest, natural area, etc. Effective IPM methods exist to contain, control, and eradicate invasive nasutes. Removing and safely disposing dead plant material and stored wood helps reduce termite food and harborage, enables liquid insecticides to penetrate soil, and facilitates access for inspections. IPM involves a combination of physical interventions including nest destruction teamed with targeted insecticide applications, followed by diligent monitoring. Fumigation is required only in unusual situations. By killing colonies and reducing overall population size, alate (swarmer) dispersal can be reduced or eliminated, thus substantially slowing—with goal of halting—infested zone expansion. This paper details specific approaches, protocols, and recommendations for detection, treatment, transport prevention, and risk-based monitoring. We present practical suggestions regarding outreach, advocacy, partnerships with stakeholders, and networking with informed professionals. All recommendations stem from the Florida Department of Agriculture and Consumer Services’ invasive conehead termite program’s best practices and lessons learned experiences during significant mitigation progress, with eradication of two populations of invasive coneheads that spread from a single introduction into Florida as an achievable goal.

Key words: conehead termites, invasive species eradication, immediate IPM responses, nest destruction, prevent dispersal

Conconehead termites, Nasutitermes corniger (Motschulsky) (Blattodea: Isoptera: Termitidae), are destructive pests, but because they build above-ground structures that help inspectors locate colonies and focus treatments, invasive populations can be eradicated if addressed swiftly. There is a narrow ‘window of opportunity’ timeline to ensure that lowest effort and expense result in best prospects for success, thus it is critical to act swiftly and aggressively. The objective of this paper is to provide guidance on best IPM approaches to address future invasive conehead termite, or other exotic Nasutitermes species, infestations if established in Florida, other U.S. states, or internationally.

Conconehead termites, named after the soldier form’s distinctive cone or teardrop-shaped head (Fig. 1), are broadly distributed in Central and South America as well as many Caribbean islands (reviewed in Scheffrahn et al. 2005a, b). In the Neotropics, N. corniger (also see N. costalis, synonymized as N. corniger by Scheffrahn et al. 2005a) is a significant pest of agricultural, structural, forest, and natural areas. Coneheads have expansive tastes, consuming dead wood from live or dead trees (including citrus and other fruits), shrubs, grasses, roots, structures, and furniture as well as cardboard and other paper products (Martorell 1945; Wolcott 1948; Harris 1961; Mill 1992; Constantino 2002; Torres 2002; Thorne 2013, 2015). The historical literature identifies this species as being a ‘major,’ ‘important,’ ‘common’ pest of fruit trees and crops such as sugar cane (Dietz and Snyder 1923, Snyder and Zetek 1934, Tucker 1939, Harris 1961, Araujo 1970, Jutsum et al. 1981, Medina-Gaud et al. 1989, Mill 1992, Constantino 2002). Conehead termites are described as ‘the single most important,’ ‘voracious’ structural pest in parts of Brazil and Argentina (Bandiera et al. 1989, Torres 2002, Constantino 2002), Panama (Dietz and Snyder 1923; Snyder and Zetek 1924, 1934), and Puerto Rico (Brooks et al. 1941). Nasutitermes corniger thrives in tropical forests, where—as in its other native habitats
such as savannas and second growth—it plays key ecological role in nutrient recycling. Scheffrahn et al. (2005b; p. 28) note that in locations where N. corniger occurs, it is often a ‘dominant species.’ Given conehead termites’ versatile capabilities to disperse, thrive, and become destructive pests across varied habitats, eradication of new invasive populations is a priority and an achievable goal, worth relatively small immediate investment to ensure immense economic and environmental savings for future generations.

Conehead termites and many Nasutitermes species are exceptionally good ‘hitchhikers,’ sneaking rides to new locations within plants or cargo transported by boat, vehicle, or plane. They are adaptable colonists with potential for survival in diverse habitats across a broad geographic range. For example, coneheads are widely distributed in New Guinea, likely transported there over 100 yr ago from the Caribbean via sugar trade shipping (Roisin and Pasteels 1986, Evans et al. 2013; see synonymy of N. polygynous and N. corniger in Miura et al. 2000). Conehead termites are also an established invasive pest in the Bahamas as well as the Turks and Caicos Islands (Scheffrahn et al. 2006).

Conehead termites established the first ever recorded breeding population in the United States in south Florida, identified in Dania Beach in May 2001. Control efforts did not begin until nearly 2yr later (Scheffrahn et al. 2002, 2014). In 2016, a second population was discovered 21 km (13 mi) north in Pompano Beach, confirmed by genetic analysis to be derived from the same single colony introduction as in Dania Beach. Human transport from one location to the other sparked the second population (Thorne et al. 2019). An essential recommendation of this paper is that conehead termite mitigation initiatives should be launched immediately upon first discovery. Successful control and containment experiences and knowledge gained by the Florida Department of Agriculture and Consumer Services (FDACS) in residential, commercial, landscape, and natural areas in south Florida inform recommendations presented in this paper. Details and chronology of the south Florida populations are reported in Scheffrahn et al. 2002, 2014; Hochmair et al. 2013; Thorne 2013, 2015; Alspach and Thorne 2015; Fenner 2017; Thorne et al. 2019, and specific examples are spotlighted in this text to illustrate IPM approaches toward mitigation.

**Conehead Termite Biology**

IPM initiatives exploit species’ biology to efficiently target aspects of their life cycle, behaviors, preferred foods and habitats, and seasonality that render the pest most vulnerable to management. A brief overview of conehead termite natural history follows, with additional details provided in text sections discussing IPM actions, along with associated rationale relevant to particular elements of this termite’s biology (for more details of conehead biology see summaries and references cited in Thorne 2015, Thorne et al. 2019).

Like ants and honeybees, termites are social insects, with a life cycle that begins with a Queen, and in the case of termites a King too, parenting a new colony (Fig. 1). Conehead termites are exceptional among nearly all other termite species worldwide, because colonies are often headed by multiple Queens (polygyny) and Kings (polyandry) (Dudley and Beaumont 1889; Barreto 1923; Dietz and Snyder 1923; Becker 1953; Thorne 1982, 1983, 2015; Clarke 1993). Multiple reproductives empower remarkable colony growth rates in coneheads because many Queens (over 50 found in single colonies in south Florida) (Thorne et al. 2019) lay eggs concurrently (Thorne 1984, Adams and Atkinson 2007). Mature nests house Queens and Kings within the royal cell, chamber(s) surrounded by harder carton positioned within the usually ellipsoid-shaped nest.

All other termite pest species in the United States (subterranean, drywood, dampwood termites, both native or invasive) remain hidden...
underground or in wood for their entire life cycle. Subterranean termites sometimes build above ground foraging tunnels, localized and far less extensive than coneheads’ gallery networks. It is thus impossible to find and treat each cryptic colony. The first phase of coneheads’ life cycle is similarly invisible to inspectors. Young conehead colonies remain concealed within wood for years during their ‘invisible’ phase while they feed locally and build population size (Becker 1953; Thorne 1984, 2013, 2015; Thorne and Haverty 2000).

Once a conehead colony is large enough to motivate quests for food and water resources away from their refuge hidden within wood, the dramatic revealing of above ground, visible activity begins. As growing ‘teenage’ colonies, coneheads build foraging tunnels that are often the first detectable sign of an infestation (Fig. 2). Extensive networks of narrow (usually half-inch wide or less) brown ‘tunnels’ or termite ‘highways’ on the sides of trees, houses, walls, or almost any surface signal where coneheads are active, primarily on or above ground. Short sections of these foraging tunnels look similar to those built by subterranean termites, but conehead gallery networks are lengthy, trekking 25 m (80 ft) or more up a tree trunk or over the eaves of a roof for example, often branching to divert foragers in different directions. Around homes, tunnels frequently track along guidelines such as mortar joints between layers of brick, or the junction between a house wall and the roof eaves. Termites are busy within these covered galleries that shelter them from ants and other enemies. Conehead workers and soldiers, each individually measure just over 3 mm (1/8 = 0.125 in.) long. They travel within the foraging tunnels day and night to reach food, water, nest, and construction resources.

Fig. 2. Conehead termite foraging tunnels showing examples of diverse substrates and circumstances where the voracious pest travels to resources. (a) Extensive network of branching trails built on a multi-trunked sea grape; (b) tunnel on exterior wall of home tracking to window air conditioner as entry point into house; (c) trail built on metal gate; (d) broken tunnel showing foraging termite traffic within; (e) tunnel extending into canopy of fruiting mango tree; (f) several tunnels, with branched galleries, on cement block front of home traveling to wood eaves and roof; (g) extensive network of foraging tunnels along with a nest (placed in white basin) between layers of stacked wooden pallets. All photos were taken in Broward County, FL.
Older conehead termite colonies disclose their colony headquarters by building conspicuous nests in addition to tunnels, further boosting humans’ ability to find them and enabling precisely directed treatments. Large colonies build dark brown nests, usually roundish or ellipsoidal with a bumpy surface (Fig. 3). The initial phase of construction creates a nest about the size of a tennis ball or softball. Healthy colonies then rapidly expand their home such that a nest the size of a basketball or even larger grow within a few months (Thorne and Haverty 2000; B.L.T., S.A., K.E.T., personal observations). Nests may be on, in, or by a tree, shrub, or structure, perched on open ground, or amidst debris. Although generally built on or above ground, conehead nests and foraging galleries can extend below the soil surface (Snyder and Zetek 1934; B.L.T., S.A., K.E.T., personal observations). A colony’s reproductives live inside a nest or within adjacent wood. The nursery containing eggs and immatures is located within the nest chambers. Foragers provision colony mates in the nest by gathering remote resources via the foraging tunnel network that radiates from the nest. A conehead termite nest constitutes the ‘heart’ of a mature colony, thus is a key strategic target of IPM initiatives (Thorne 2013, 2015; Alspach and Thorne 2015; Thorne et al. 2019).

As population size increases, mature conehead colonies can expand from their original nest by building and populating ‘satellite’ nests that can be more than 30 m (98.4 ft) apart. Single colonies have been documented occupying 52 nests (Atkinson and Adams 1997). Alates from the original nest can walk over and become Queen(s) and King(s) in the satellites (these particular reproductives skip the alate flight and interbreed). Thus, a single intermingling colony may be polydomous, constructing, and occupying a network of nests (Dietz and Snyder 1923; Thorne 1982, 1984; Levings and Adams 1984; Roisin and Pasteels 1986; Adams and Levings 1987; Clarke 1993; Atkinson and Adams 1997; Thorne and Haverty 2000; Adams and Atkinson 2007).

Fig. 3. Photos highlighting example conehead termite nest locations, size, and appearance. (a) Arboreal nest built on broken branch of large Brazilian pepper tree; (b) nest in roof eaves of home, exposed to view when ceiling was removed; (c) mound nest built on ground, surrounding a decaying stump; (d) thriving nest built within wheel well of boat trailer; (e) two of seven lobes of a nest in dying tree; (f) cross-section of cut (dead) nest showing interior galleries; (g) nest built on ground with vines and small branches enveloped by the nest carton; (h) one of two nests constructed within pile of railroad ties, later transported to inadvertently spark a new infestation. All photos were taken in Broward County, FL.
Conehead termite workers and soldiers are sterile. Winged female and male swarvers (alates) develop to fly during the species’ annual mating season (Fig. 1). Conehead alates have partially translucent black (‘charcoal colored’) wings. In the Neotropics and south Florida, the major mating flights typically occur around twilight following the first heavy rains of the spring wet season (Dudley and Beaumont 1889; Barreto 1923; Dietz and Snyder 1923; Becker 1953; Thorne 1983, 2015; Clarke 1993). Large colonies can produce over 20,000 winged alates to disperse in one flight season (Thorne 1983, Roisin and Pastres 1986, Adams and Atkinson 2007). Swarvers fly from on or near their nest, dispersing as early as the first year that a nest appears. Once they land they find mates, become the Queens and Kings of new colonies, and the colony life cycle begins anew.

Scheffrahn et al. (2005a) report soldier body length, based on individuals measured from a variety of locations, as 2.85–5.23 mm (0.11–0.20 in). They describe female alate length without wings as 6.92–8.65 mm (0.27–0.34 in) and male alate length without wings as 5.85–7.45 mm (0.23–0.29 in).

This paper leads with the highest priority first response control measures that should be implemented ‘immediately’ upon discovery of a new population of coneheads, or any species of Nasutitermes. The remainder of the paper elaborates IPM actions, tools, outreach, and partnerships toward effective containment and control drawing upon lessons learned from the invasive conehead termite eradication program led by FDACS in south Florida.

‘First Five’ Responses: Immediate Actions When Nasutitermes is Discovered at a New Location

The following five priority response actions should be launched within days or weeks of first discovery of an invasive conehead termite infestation (responses 2 and 3 may not fit all situations). These are swift, inexpensive actions that will have immense impacts in beginning to control, and quickly working to contain, the exotic population.

1. Confirm identification of the suspected conehead termites

Identify at least to genus; it is not urgent to determine exactly which species of Nasutitermes has invaded. Possible resources for securing this taxonomic identification directly or via referral to an appropriate expert include University entomology faculty or staff, extension office professionals, or a pest management company.

Photos of the suspected coneheads along with their tunnels and nest are useful for identification, but it is best to also have preserved insect specimens to show to experts and retain as voucher samples. Because termites have soft bodies, collected individuals will shrivel as they dry, then often disintegrate unless placed in liquid preservative. If scientific supplies of alcohol and leak-proof vials are unavailable, practical options for storing termites include placing them in a zip-lock plastic bag with rubbing alcohol (as for cleaning wounds), hand sanitizer containing alcohol, or even gin, vodka, or rum. Place at least 10 insects, especially including soldiers and winged forms if present, in the plastic bag or other small plastic or glass watertight container along with ample alcohol-based liquid. Transfer samples to 100% or at least 70% ethanol as soon as possible following field collection. If the specimens are sent to a taxonomist for determination, mail in a crush-proof box.

2. If the infestation is on a boat or other isolated situation (e.g., one structure), fumigate

The remainder of this paper will address Nasutitermes established on land, but if the infestation appears to be completely or largely confined to a single unit or location, such as a yacht, shipping container, or building, fumigation is a great tool for rapid control. Fumigation offers no residual protection once the toxic gas dissipates, so inspections for active conehead tunnels or evidence of survival in the area must continue, but early fumigation of an infested entity can put the brakes on an invasion.

3. If the termites are found within a month of flight season, destroy known nests and, if possible, treat immediately

Halting dispersal flights is a time sensitive priority, especially if within a month of the start of flight season and one or more conehead nests are located. Even relatively small, young nests can produce swarvers. To avoid risk of dispersal flights, nests and the termites within them must be destroyed—first by swiftly prying the carton nest from its attachment site and, immediately, physically crushing the carton (stomping on nest pieces works well), then treating the crushed material and removed nest’s original location (‘footprint’) if possible (Fig. 4; see Nest Removal and Destruction section). If an insecticide application is infeasible, proceed with ‘emergency smash only’ (ESO) destruction and crushing of the nest. Protocols for nest destruction including ESO, and subsequent insecticide treatment of nest sites if possible, are elaborated in this paper’s IPM section. Most mature or developing alates reside in the carton nest and their behavior is to perch on or near the nest prior to taking flight, so exterminating the nest population is a huge assist toward minimizing dispersal risk (Thorne 2013, 2015; Alspach and Thorne 2015; Thorne et al. 2019).

If alate flights are prevented, this termiti can expand its range only by walking or transport.

To suppress population growth and minimize satellite nest extensions, destroying all known nests and treating their original locations with liquid insecticide are high priority control efforts no matter what the season. Crushing nests and their population as flight season approaches or occurs is a critical priority. Dispersal flights in the tropics or subtropics typically occur in spring when the wet season begins, but if in a location with a less defined rainy versus dry season it is best not to take chances and proceed as quickly as possible with nest destruction (even if ESO). Invasive species out of their natural range and season cycle often adapt and improvise, adjusting their behaviors and phenology in unpredictable ways. The safest way to prevent dispersal flights is to destroy all known nests.

4. Notify property owners, residents, and employees to prevent transport of potentially infested materials

A critical aspect of an invasive conehead containment program is preventing reproductives, or entire colonies, from ‘hitchhiking’ via human transport to colonize another location. If infested materials harboring conehead termites are moved and left at a different site for even one night, the opportunistic N. corniger, including reproductives, can relocate enough of their colony to ‘spark’ an invasion of the new area. That possibility must be eliminated by preventing relocation of trees and shrubs, cut branches and wood debris, railroad ties, and wooden furniture or pallets out of infested and surrounding locations. Cellulose waste from the infestation zone must be responsibly disposed, preferably in an incinerator, or shredded, or buried in a landfill...
the same day as dumped (Table 1). Property owners, residents, and everyone who works on conehead termite infested properties must be informed about the situation, including exactly what to look for (foraging tunnels, nests) and who to contact if they find new pockets of infestation. They must also receive clear, practical instructions regarding proper disposal of all cellulose materials discarded from the properties (see Containment section).

5. Inspect and map extent of the (visible) infestation

Understanding the size and distribution of an infestation provides a baseline to inform planning to address the invasive population. Inspecting and marking all known infested as well as surrounding properties (eventually out 0.4 km [0.25 mi]; see Survey section and Table 2), searching all buildings and landscapes of each, to create even a ‘general sketch’ map of conehead nests and activity provides an essential framework of scope and density of the issue. Precise maps using GPS data will be helpful follow-ups, but overview analysis of where the termites are present, absent, and with ‘hot spots’ of activity identified will focus effort and decisions toward containment, control, and eradication.

Once the ‘First Five’ immediate responses are accomplished, an invasive conehead termite eradication effort is ready to move on to a thorough, aggressive IPM program. Having launched the critical containment actions to prevent alate dispersal or transport of infested materials (First Five responses 3 and 4), and scouted carefully to glean a sense of extent of the infestation (First Five response 5), the team can pause briefly to assess and plan its comprehensive approach toward eradication. Next steps to accomplish that plan follow.

### Inspection Surveys

Locating and mapping sites and extent of invasive conehead infestations through systematic visual surveys are a first priority when...
new populations are found. Inspectors must be trained to identify conehead soldiers (Fig. 1), tunnels (Fig. 2), and nests (Fig. 3), and to distinguish coneheads if other termite species or ants in the area could be confused with those diagnostics. Conehead foraging tunnels are the most common, distinctive indicators of an infestation. If mature colonies are present, sometimes expansive tunnel networks may be tracked to one or more carton nests. However, young colonies remain hidden within wood, venturing out by first building just a few foraging tunnels. To reach food and water sources, conehead termites build tunnels on or over any surface, on plants anywhere from their roots to canopy, and on wood, metal, plastic, concrete, or on the soil surface.

Large conehead termite colonies construct carton nests built on many different substrates and in diverse locations, including tree trunks, branches, at the junction of the trunk and ground at the base of a tree or shrub, or directly on the soil surface (often anchored to a hidden root or stump). In addition to woody vegetation or grasses, nests may also be constructed on, in, or under a structure (including within wall voids or on roof joists). Nests may be on or under other footings such as plywood, pallets, roofing panels or similar harborage or concrete blocks, especially if they are on the ground. Aged treated woods, such as railroad ties or pressure-treated timbers may host conehead termites. In short, inspections must be meticulously thorough as coneheads are remarkably flexible in habitat selection.

Flagging locations of foraging tunnels and nests, and mapping their positions (using different symbols for tunnels vs nests) via GPS coordinates will expedite relocating those sites for treatment and inspections (Table 2).

| Tool | Example Uses |
|------|--------------|
| Position markers to signal field locations (such as flagging tape, spray paint, stakes, or other visible field signs) | Visible signals to flag nest, tunnel, and treatment locations. It is also helpful to mark access routes through dense vegetation; may note date and key information on position markers using permanent ink pen |
| Flashlight | Inspect cavities such as tree hollows, under structures, or any dark void |
| Gloves | For safety and cleanliness while surveying; thin gloves best for tactile tunnel search |
| GPS or other mapping technology | Record locations of conehead activity and treatments; helpful for creating accurate maps |
| Camera (with video helpful) | To document infestations, treatments, site cleaning actions, etc. for education and outreach |
| Hand-held pruning shears | Trim small plants to facilitate inspections, nest removal, and treatments |
| Long handled (e.g., 61–71 cm; 24–28 in) garden lopper | Prune branches, stems, roots, vines for survey, nest removal, and treatment access |
| Medium to large blade shovel | Remove large nests; pry off sections of difficult to reach nests. Following nest destruction, use shovel to turn crushed carton so insecticide spray reaches all nest material |
| Small blade shovel or trowel | For precision work, facilitates removal of small nests or remaining chunks of carton. Also useful for dicing carton to find, extract, and crush denser nest portion harboring royal cell and reproductives (locating and destroying the royal cell minimizes risk of Queens and Kings fleeing deep into host wood) |
| Blunt-tipped knife with blade extending into handle (simple dinner knife works well) | Long, thin, strong tool to help probe, scrape, or pry during surveying and carton destruction within tight spaces. A jack knife blade may break when twisted to pry nest carton or wood. A flathead screwdriver is an alternative probe, but knife blade better for prying |
| ~18–14 in. length of rebar or long shank screwdriver | Long reach inspection probe, or for smashing carton within a deep void or hollow tree trunk |
| Sledgehammer | Sometimes helpful to smash older, dense nests |

These are examples of readily available, inexpensive tools useful for field team members during inspections and nest destruction.

...and eradication program. When surveying, inspectors must thoroughly examine all trees, shrubs, logs, stumps, and other vegetation such as grass clumps, accumulated leaf litter, and visible roots. Checking trees for coneheads requires scanning the entire base of the tree, especially at the junction with soil, pulling away neighboring plants that obstruct view of the trunk, and probing the soil surface to expose hidden termites. A full perimeter check of each tree trunk is crucial, especially examining crevices in the bark that may hide conehead foraging tunnels. Knotholes and injury scars where a tree’s branches have fallen off or been pruned offer access into the tree and are common points of entry for conehead tunnels. The tree canopy may host conehead tunnels or nest(s), so look up, down, and from various angles to fully survey tall plants. Litter on the ground can be thick and varied, including twigs and decaying branches that may harbor coneheads, sometimes with reproductives and brood. Search through portions of dense litter and break occasional small pieces of wood to reveal conehead activity if present.

Buildings must be carefully inspected for coneheads, especially for tunnels on walls, along roof eaves, window and door molding, the junction of the foundation sill plate or siding, and anywhere air conditioning condensation or other moisture accumulates. Look indoors, in the attic, and under the structure too if accessible, for tunnels and nests. Fences, outdoor wooden furniture, wooden garden tool handles, and debris in landscapes must be checked. Lift objects covering the ground, such as buckets, pavers or stones, or even refuse (an old suitcase with a side against soil, for example) because moisture and protection under those items may be hospitable to coneheads.

Trees with smooth bark or walls that are flat and painted are relatively quick to survey; deeply grooved tree bark or dense, complicated vegetation and cluttered areas require detailed, slower inspections. Most surveys are visual, but touch is a helpful technique...
for some surfaces. For example, foraging tunnels may be built on the underside of branches or wooden fence rails. For fence surveys, instead of bending over to view the underside of each rail, raised, thin termite tunnels may be detected by carefully running a thinly gloved hand along the base of each piece of wood. If in an area with venomous creatures that may hide in cryptic locations, use a flashlight to inspect dark cavities, assisted by a mirror to see under fence rails or similar features.

Survey Area and Surrounding Distance Rationale

While properties known to have been infested with conehead termites and those immediately adjacent are highest priority, annually surveying the surrounding area out at least 0.4 km (0.25 mi) in each direction is an important driver of program success. The goal of an ‘expanded’ survey surrounding current or previously infested areas is to find conehead colonies resulting from alate dispersal flights. The distance recommendation is an appropriate balance between the pragmatic practicalities of inspection costs (money and time) versus conservative but acceptable risks regarding conehead alates dispersing farther than 0.4 km and successfully founding a colony. Due to recent discovery of an additional infestation in a mangrove wetland in Dania Beach, following over 2 yr of no live coneheads found in that city, we advocate inspection of natural or heavily overgrown areas out to 0.8 km (0.5 mi) from previous infestations, doubling the generally recommended extended inspection distance. Dense vegetation (forests, mixed vegetation, and grasslands) are particularly hospitable for conehead survival and population growth, and with less human activity traversing thick vegetation, conehead colonists may grow large populations without notice.

It is important to ensure that residents out at least 0.8 km (0.5 mi) are well informed about signs of conehead termite activity and how to report potential infestations. This can be conducted primarily through outreach efforts rather than direct surveying. No scientific study has examined maximum flight distance of any species in the conehead genus, anywhere in the world. We, therefore, used the most accurate termite alate flight data available as a guideline. Two studies examined flight distance of alates of the invasive Formosan termite (Coptotermes formosanus) within the United States. Rust et al. (1998) reported that while ‘most trapped alates were caught within 0.15 km (500 ft) of where they emerged,’ the researchers collected ‘some alates at light traps as far as 892 m (2,926.5 ft; 0.55 mi) from the original (exotic) infestation.’ Marking individual alates prior to release, Messenger and Mullins (2005) documented that C. formosanus alates dispersed as far as 892 m (2,926.5 ft; 0.55 mi) from their launch site.

Almost certainly N. corniger has a similar dispersal distance profile as Rust et al. (1998) note for C. formosanus (also documented for other termite species), i.e., that the majority of alates land relatively near their original nest, with far fewer flying or being blown much further. To be conservative, we doubled the 0.15 km (500 ft) distance that Rust et al. (1998) record as the outer margin distance for ‘most alates’ to travel. We thus assume that 0.3 km (1,000 ft or 0.19 mi), delineates the boundary within which the vast majority of N. corniger alates would land following dispersal flight. The ‘out to 0.4 km (0.25 mi)’ expanded survey distance (and out to 0.8 km [0.5 mi] for natural or overgrown areas) thus conservatively encompasses and buffers that ‘most likely’ distance.

For a conehead colony to be successfully established by alates, and then to survive and thrive to the point of reproducing and continuing to spread the infestation, a sequence of successes must occur. Individual alates must disperse from the natal nest; avoid predation while flying or alighting; find a mate; quickly locate a colony-founding site with sufficient protection, food, and moisture; dodge attack by ants, fungi, and other predators, competitors, and pathogens; and found a colony that survives at least several years to sufficient maturity that it successfully reproduces to further spread the exotic infestation. Each of these steps has a very low probability of achievement in any particular instance. Having each stage of conehead alate dispersal and successful new colony maturity occur is a series of very low probabilities, each multiplied by the previous one, meaning a very low ultimate chance of success. There is thus a miniscule, although not zero, chance that a conehead colony would be successfully established by alates dispersing more than 0.4 km (0.25 mi), compounded by even lower probability that any such colony would survive to produce alates.

Follow-Up Inspections and Risk-Based Surveys

A backbone of a successful invasive conehead termite eradication program is monitoring for persisting, resurging, or newly detectable young conehead colonies as they become evident by building visible foraging tunnels and nests. Although the nest destruction and treatment protocol has strong success in exterminating conehead colonies, population resurgence in a treated location may occur because: 1) reproductives survived nest destruction and insecticide application by retreat into cavities within adjacent wood and/or 2) workers and soldiers foraging away from the nest at the time of treatment regroup to establish a new hub following destruction of their original nest. Post-treatment monitoring is essential to catch survivors (or young colonies previously hidden within wood, recently growing large enough to build visible tunnels and nest). Colony regrowth can be rapid; a nest may be reconstructed in several months, or in other cases rebounding may be considerably slower.

The frequency and locations of inspection surveys are based on relative risk of infestation or reinfestation of a property or area. Risk level is determined by two factors: time since live coneheads were found and distance from a known infestation. High-risk properties currently have live coneheads, have had activity within the past year, or are adjacent to active sites. We recommend that high-risk areas be surveyed every 4 mo. Medium risk locations had live coneheads but no activity has been found for at least 1 yr. Low-risk properties are within 0.4 km (0.25 mi) of active or previously active locations. Medium and low-risk sites are surveyed annually. We recommend continuing annual surveys of all at-risk conehead termite properties (those with known previous activity and out 0.4 km [0.25 mi], extending out to 0.8 km [0.5 mi] for natural or overgrown areas) for at a minimum of 10 yr after the last live N. corniger is found in that area.

Timing follow-up surveys strategically during the calendar year can improve efficiency of locating and treating new or resurging colonies. In their native habitats and in south Florida, conehead termite alates fly following the first substantial rains of the wet season. Conducting the broad ‘expanded’ survey several months earlier allows time to coordinate and treat any infestations discovered before colonies swarm.

IPM Approaches to Invasive Conehead Termite Eradication

As discussed previously (also see Containment section), overarching priorities for an invasive conehead termite eradication program are to prevent spread by stopping alate flights and transport of infested
items. Whether preparing for first treatment of the invasion or later treatments of newly discovered or persisting sites of activity, begin by determining whether ‘emergency’ actions are required for high-risk infestation containment. Immediate actions may be prescribed if nearing alate flight season or circumstances are otherwise too time-sensitive to allow a comprehensive treatment (see Steps 3 and 4 of ‘First Five’ actions discussed earlier). After assessing and addressing urgent containment issues, the following operational recommendations are effective IPM methodologies for containing, controlling, and eradicating conehead termites. Regarding insecticide applications, ensure that treatments are made by licensed professionals according to the label and in alignment with federal, state, and local regulations.

**Site Management: Reduce Conehead Resources, Improve Access for Inspections and Treatments**

Dense vegetation and cellulose debris on overgrown properties provide abundant food and harborage for coneheads. Layers of branches and thick foliage obstruct access, complicate visual inspections and treatments, and compromise efficacy of targeted insecticide treatments. Removing dead plant debris, trimming trees and bushes, clearing vines, cleaning up trash, mowing, and then responsibly disposing of materials to prevent conehead transport (see Containment section; Table 1), are IPM strategies that address these issues. Depleting conehead food and harborage by cleaning a site requires an up-front investment of time and money, but such initiatives pay off quickly by substantially reducing manpower and insecticides required to control an infestation. Site cleanup and maintenance greatly accelerate the timeline and prospects for success.

In most instances, landowners and residents are helpful in reducing conducive conditions on their properties once informed about the issues. Basic efforts such as pruning dead branches, mowing, weed whacking vegetation, and picking up trash reduce hospitality to coneheads and improve access for surveys and treatments. It is crucial to educate and assist in responsibly disposing of cleaned-up debris to ensure no live termites are moved from infested to uninfested areas.

As an example of how site management can expedite control of an intense conehead termite invasion, FDACS addressed very high conehead population density on 1.4 hectares (3.5 acres) in Broward County, FL. This parcel had no structures, but was covered with exceptionally dense invasive hardwoods, predominantly Brazilian pepper trees, and the termites had year-round water from a pond and canals. When coneheads were first discovered on the boundaries of the property, the interior was largely inaccessible due to complex, impenetrable vegetation, enabling limited surveys and restricting treatments to mostly backpack sprayer applications. Exploratory footpaths cut through several portions of the property revealed 21 large nests, as well as active foraging tunnels throughout the entire reachable portions of the parcel. Risk of alate flights launching dispersal to neighboring uninfested properties motivated bushwhacking to reach, destroy, and treat as many large nests as we could find, along with plans for clearing and cleaning the property.

FDACS’ conehead termite eradication program, assisted by the Florida Forest Service, the Broward County Water Management Division, Broward County Public Schools, and a grant from the United States Department of Agriculture (USDA), employed multiple landscape services to clean this property. Actions included mowing, weed-whacking, pruning dead portions of trees, raking (often manually) small branches and litter into piles, chipping the smaller debris as well as large dead branches, cutting and chipping large (invasive) Brazilian pepper trees, grinding tree stumps, shredding dead palm trunks and fronds, and maintenance mowing to retain inhospitable conditions for any surviving hidden coneheads and a cleared landscape to facilitate future surveys.

All dead wood throughout the property was either pulverized in place (e.g., stump grinding) or collected and chipped on-site using equipment that created small chips. Small chip size (goal no greater than 2.0 x 12.7 cm, 0.7 x 5.0 in) is critical to destroy the integrity of conehead colonies in the vegetative material. Even if rare individual termites survive in little chunks after chipping, the probability they could endure the heat generated by decomposing wood chips and find enough colony mates to thrive is negligible. Piles of chips were left undisturbed for 5 mo to compost, then spread in a thin (goal no thicker than 15 cm or 6 in.) layer. Handling vegetative debris in this manner eliminated possible transport of conehead termites off the property, and reduced project costs for fumigation, debris collection, transport, and landfill disposal of infested plant material (Table 1). FDACS staff worked closely with the contractors to ensure compliance with risk-based program goals designed uniquely for this project, including appropriate chip size, temporary on-site storage locations, and particularly that no vegetation was removed from the property.

Since substantial termite harborage and foraging resources were removed, only one resurgence of live conehead termites has been found, and swiftly treated, on the property (17 mo as of this writing). Before the intensive site cleanup, FDACS had treated conehead termites on this property for over 3 yr, including treatment of 88 nests the year prior, yet heavy activity persisted. Site cleanup combined with insecticide treatments silenced conehead activity in 7 mo, confirming efficacy of this strategy. Surveillance will continue in case young conehead colonies remain hidden within remaining trees, shrubs or roots, but the dramatic result of population suppression represents an immense leap forward in a short amount of time due to clearing dense vegetation and debris.

Cleaning overgrown infested properties facilitates invasive conehead termite control, but if funding or permissions prohibit clearing, control remains feasible. The following sections discuss control methods to advance eradication in conjunction with, or independent of, site cleanups.

**Addressing Conehead Nests and Foraging Tunnels**

Following thorough survey mapping and flagging the location of all nests, launch nest removal, destruction, and insecticide applications as soon as possible. A team of three people is efficient to implement this treatment sequence. One person locates nests flagged by the survey team and records required data for each site. Two people, at least one a certified pest management professional, follow closely to remove and destroy nests, then immediately treat with liquid insecticide each nest site and the crushed nest carton.

**Nest Removal and Destruction**

Treatments begin with the removal of a nest from its host wood, smashing the carton to kill most inhabitants, and spraying the disintegrated carton with insecticide. Evaluate best access angles and efficient ways to pry off the entire nest, or large sections, given the nest’s shape, position, how the nest is anchored around roots, limbs, or tree trunk. Termites within the nest, including reproductives, will be alarmed and swiftly begin vacating the nest as soon as they sense...
vibrations, so best to first observe how the nest is situated and plan your strategy before touching the carton.

Begin nest removal by quickly clearing obstructions, such as branches, leaf litter, and trash that might impede extraction. Next, pry carton away from points of attachment using tools appropriate for the size and location of the nest—hatchet, shovel, trowel, or small knife, for example (Fig. 4). Termites will stream onto the nest exterior and attempt to escape in every direction once nest removal begins. If you see Queens or Kings, do your best to prevent them from retreating into cavities in wood or soil; reproductives are highest priority to exterminate. Coneheads do not bite or sting. A swift, efficient removal process accomplished before too many termites retreat into solid wood or ground adjacent to the nest is optimal. However, if things get complicated while removing carton from substrate, keep working until finished, digging and probing to do your best to extract (or crush in place if difficult to reach) all carton. Inaccessible voids with carton can be smashed in place using thin probes such as a handy length of rebar or a long shank screwdriver (Table 2).

Once the nest has been removed or even while one person completes finer scale carton extraction, aggressively stomp on and/or use thin probes (e.g., shovel, sledgehammer; Table 2) to smash removed nest carton and associated termites. Crushing must disintegrate carton into coarse-sand-sized pieces. This physical smashing will kill most of the termites. Crushing nest galleries also eliminates the risk of recolonization of intact carton by surviving coneheads (such as those out foraging well away from the nest), and prevents a different colony establishing in abandoned carton in the future (which is possible even in treated carton once the insecticide degrades). After nest pieces have been demolished, spray all disintegrated material and termites with insecticide. Use a shovel to remix the material and spray again to reach all angles and active coneheads.

In the south Florida invasive populations, nearly all N. corniger nests were small-to-modest sized (nearly all 40 cm or less in diameter) compared with sizes achieved by older nests in their native range (Dietz and Snyder 1923; Wolcott 1948, Thorne 1984, Clarke 1993). Florida nests had carton thin and fragile enough to crush with little effort and without special equipment. While careful inspections to find nests can be time consuming, destruction of the relatively young, not-yet-densely-reinforced nests typical of recent invasions is quick. An immense logistical advantage in addressing the Florida invasions was that no nests were found above 20 ft high (off the ground); most were built much lower or on the ground. Thus, nests in Florida were accessible for removal, destruction, and treatment, in contrast to those constructed high in forest canopies as occurs in much of the species’ range (Emerson 1938, Thorne 2013).

**Rationale for Nest Removal and Destruction IPM Methodology**

In the early stages of FDACS’ eradication program, the nest treatment protocol was to leave conehead nests in place. Each was treated by spraying liquid insecticide on the exterior and by inserting an injection tool into the carton to apply insecticide to the nest interior. However, due to the hydrophobic nature of conehead termite carton (nests retain dry interiors even after heavy tropical rainstorms) (Dietz and Snyder 1923; Thorne et al. 1996, 2019), insecticide did not penetrate deeply or broadly. In many cases retreats were required due to activity resurgence.

During 2012, the nest treatment protocol was modified to lead with a logical and powerful nonchemical IPM action—physically removing and destroying entire nests and the conehead population they house. Directed liquid insecticide application to the crushed nest carton, nest site, and surrounding residual conehead activity follows immediately. This protocol has been quick and effective, resulting in few retreats.

The rationale for this approach is that nests are the ‘heart’ of conehead colonies, normally containing the reproductives, eggs and nursery, and up to several hundred thousand soldiers, workers, and potentially prealates and/or alates. Although termites traveling and foraging outside the nest will be left behind, removing and crushing the nest dramatically reduces the chance that reproductives will develop to revitalize the remaining population. Furthermore, the severe ‘injury’ depleting the colony population and demolishing its home markedly reduces the probability that it will produce alates that could spread the invasive population.

**Insecticide Treatments of a Removed Nest’s ‘Footprint’**

The ‘footprint’ is the underlying area of attachment exposed when a nest is removed from wood, soil, or other substrate on which it was built. Treat the ‘footprint’ where the nest sat, extending insecticide spray out 0.6 m (24 in) surrounding the perimeter of the nest footprint. In most cases, nest removal reveals one or more holes or voids penetrating into the wood or plant material on which the nest was perched. Reproductive and other colony members will make every effort to escape into those access ports as they retreat from nest disturbance. It is critical to treat those harborage or getaway voids by power spraying or injecting insecticide directly into them immediately following nest removal and destruction. Following nest removal, treat the soil out to 0.6 m (24 in) surrounding the entire perimeter of the base of the structure that held the nest.

Conehead termites may build nests in the roots of plants and trees including dense bunch grasses. When this occurs, after removing nest carton, apply a liquid insecticide labeled to permit direct application to the root area via drench or rod injection.

**Emergency Smash Only (ESO) Nest Treatment**

Whenever possible, it is best to have a licensed pest management professional on site to treat immediately following conehead nest removal and destruction. However, the ESO insecticide-free protocol should be used as an important stopgap procedure in time-critical situations (such as before and during swarm season) if insecticide application must be delayed.

The emergency process follows the method discussed in the Rationale for Nest Removal and Destruction Protocol section: dislodge the nest from its substrate, place carton sections on the ground, and smash to completely disintegrate the nest galleries and kill as many inhabitants as possible. Because insecticides will not be applied immediately to the crushed carton, repeated crushing, turning and repositioning the material with a shovel, and re-crushing is important to physically kill as many termites as possible. An ESO procedure demolishes the majority of pre-alate nymphs and alates.

As soon as possible following an ESO, insecticide treatment of the nest footprint substrate and surrounding area should proceed as if applied immediately after nest destruction. Monitoring ESO sites and surrounding areas is especially important because the risk of surviving colony members rebuilding a nest in the same or a nearby location is higher than following the complete nest removal, smash, swift insecticide treatment sequence.

**Treating Foraging Tunnels**

Foraging tunnels channel coneheads to the soil and litter surrounding the tree, stump, fencepost, structure, or other substrate upon which the tunnels are built. Do not treat the tunnels directly (see below for rationale). Instead, the soil surface around the entire
perimeter of that wood, building, or substrate should be sprayed with nonrepellent insecticide out to 0.6 m (24 in). That conventional surface treatment application (not injection rodded into soil, merely surface spray) forces termites to travel over or partially through treated substrate where they contact the insecticide. Regardless of location of tunnel(s), it is imperative to treat the entire perimeter of the tunnels’ host tree or shrub trunk, stump, structure, or other object. Untreated gaps in surrounding soil (an incomplete barrier treatment) allow coneheads to bypass treated soil. Untreated soil creates safe outlets through which coneheads may relocate their tunnels to flee an infested structure or plant to forage elsewhere, or they may build new tunnels through untreated ‘gates’ to reenter the original resource from a different direction.

Conehead termites can travel through vegetation, across a wire, or over other elevated conduits to escape even if the structure or tree they infested has a complete soil perimeter treatment. If such alternate exit routes exist and cannot be eliminated by pruning or otherwise altering the landscape or other buildings in the vicinity of the treated structure must be routinely monitored for newly constructed tunnels.

Foraging tunnels with no visible connection to the ground are common on trees and structures. Tunnels may enter a tree trunk through above ground scars where branches fell off or were cut, lesions in bark, or other voids. They access structures through cracks and crevices in wood, molding, eaves, or siding. If tunnels that do not reach the ground are found, it is still a best practice to treat the soil around the entire perimeter of the infested tree or structure as above since traveling to the ground is a logical exit move. Also inject, spray, or otherwise direct insecticide into reachable foraging tunnel entry points into the wood, as with treatment of holes and ‘escape routes’ into wood or ground found under the ‘footprint’ of a removed nest.

When only one or a couple of foraging tunnels are found in relative isolation, they may be the earliest visible signs of a young colony still hidden within wood. Treat the tunnels as above, GPS the location, and make note of this area for future monitoring.

Rationale for Treating Foraging Tunnels Indirectly
In most cases, conehead termite foraging tunnels are not treated directly for three reasons. First, the sections of tunnel that a human can see or reach represent a small fraction of the total length of a colony’s foraging gallery network. Even if a nonrepellent insecticide is applied to a tunnel surface, termites will abandon the drenched section of the tunnel and are deterred from building over the chemically treated area. That response makes it difficult to determine whether unoccupied remaining tunnels are empty due to termite death, or if the coneheads simply abandoned that stretch of ‘highway’ and rebuilt their gallery system elsewhere. We observed tunnel relocation behavior by coneheads, without noticeable suppression of activity, many times in south Florida following direct spray of liquid insecticides on foraging tunnels. Similar ineffective results occurred when insecticidal dust (active ingredient fipronil) was puffed into tunnels.

The second reason to retain the integrity of active tunnels and leave them relatively undisturbed is to take advantage of their natural function as ‘highways’ that direct unsuspecting coneheads into treated soils and other substrates. Thirdly, untreated, active foraging trails left relatively undisturbed serve as an important indicator tool for follow-up monitoring. Checking whether tunnels remain active assesses impact of a nest, soil, or litter treatment program. It also provides a more reliable indicator of efficacy than if tunnel integrity is destroyed by insecticide drench, and/or physically scraped off, which often results in the termites vacating that route and constructing tunnels elsewhere.

Treatment of Conehead Termites Foraging in Ground Debris
Conehead termites can thrive in ground surface litter layers comprised of decomposing leaves, plant debris including small stumps and fallen branches, and/or refuse timber wood. These often moist, complex habitats comprising many shapes and sizes of cellulose can be hotspots of foraging termite activity. Foragers, or even entire small colonies, may cluster in stumps or pieces of wood; and broadly scattered foraging traffic may extend seemingly throughout a wide area rather than in narrow tunnels.

Treat foragers in undisturbed litter before clearing this infested surface-layer debris. To treat conehead foragers within litter layers, FDCAs contracted a licensed applicator to use nonrepellent insecticides (Table 3). The equipment was calibrated to produce a uniform, coarse droplet spray, using a low pressure setting to eliminate off target drift. If possible, it is best to spray enough chemical to coat most of the litter and reach the soil surface beneath it. In many instances, however, liquid insecticide did not reach the soil, but still achieved complete control of the termites in the litter.

Fumigation
Fumigation of conehead termite infestations is usually not necessary, but in some situations, it can be a helpful strategy. When fumigation is used, it achieves quick, effective elimination of all termites under the tarp. Fumigation of conehead termites with sulfuryl fluoride requires a licensed applicator to use a 1x rate (label dosage factor [accumulated ounce hours of exposure] as a multiple of that needed to kill drywood termites; i.e., the application rate for conehead termites is the same as for drywood termites (Table 3). It is important to remember that there is no residual protection once the tarp is removed so postfumigation protective treatments may be warranted along with visual surveys to monitor for activity. If fumigated materials are removed from a property, they must be loaded and transported off-site the same day tarps are pulled. Any cellulose remaining for even a single night on the fumigated property could be reinfested by coneheads surviving outside of the tarped area (Table 1).

Fumigation is warranted if an active infestation within a structure (home, shed, office building, warehouse) is extensive and complicated, including the presence of one or more difficult-to-reach nests, perhaps with entangled attachment around joists or beams, and/or an extensive network of active foraging galleries leading into wood, voids, and inaccessible or cluttered areas. As an example, in Florida a commercial multiunit storage facility was infested; conehead termite tunnels were evident in the hallways between extensively packed units. It would have been impossible to find and adequately address all nests and foraging termites, therefore, the entire building was fumigated. After the tarp was removed, the surface of soil surrounding the building perimeter was sprayed with a nonrepellent insecticide to preclude movement of termites back into the building.

When an infestation appears to be completely or largely confined to a single unit or location, such as a yacht, building, or vehicle, fumigation may be the best mechanism for swiftly eliminating the colony. As an example, an undriveable dump truck contained a full load of conehead termite infested trash in its bed. Instead of
removing and treating the trash, the entire truck was tarped and fumigated which efficiently and quickly eliminated the infestation.

Finally, fumigation may be useful for eliminating the risk of moving coneheads to new locations by treating infested items before transporting for disposal. During the cleaning of a heavily infested property in Broward County, trash and debris were placed in a large dumpster on-site. The dumpster was fumigated before being taken to the landfill for disposal to kill all coneheads before leaving the property.

**Baits**

Baits are a logical tool to address pest termite infestations. In principle, if a termiticidal bait is consumed in sufficient quantity by worker termites, they will spread the toxin to colony mates through social interaction, ultimately resulting in suppression if not elimination of their colony. In practice, however, termite bait systems are less predictable than liquid insecticide applications. Because termites may focus their attention on other available resources in their local environment, baits can take many months to be discovered. Then, even if a colony recruits to the bait and sustains feeding, the slow acting insecticides can take a long time to significantly impact population size.

Termite baiting in general, and in particular when the active ingredient is a molt disruptor, has been less effective against Termitidae (‘higher termites’) than when targeting subterranean termites. Less successful, slower timeline population impacts of baits attempting to control Termitidae such as *Nasutitermes* and *Macrotermes* have been attributed to their markedly different physiology, digestive symbionts, molt frequency, food selection, and social behavior (summarized in Webb and McClintock 2015; also see Evans and Iqbal 2015) relative to Rhinotermitidae.

To control invasive infestations priorities are speed and reliability of treatments. In south Florida we used liquid insecticide wherever possible because efficacy was swift, strong, and conehead activity typically enables precisely targeted spray or injection applications.

There were situations, however, where persistent, complicated conehead infestations compelled our program to try bait systems. These problematic circumstances included conehead activity deep within tree trunks (positions difficult to reach with liquid insecticides) and exceptionally difficult to access locations where we could not find a nest but noticed low levels of foraging tunnel activity.

To date, during the south Florida eradication program, we placed 21 above-ground bait stations, active ingredient noviflumuron across 14 locations. Results were promising at several locations, but overall equivocal due to lack of controls and varying placement durations. We interrupted baiting immediately if other options for treatment or responsible removal of infested materials became available. In this eradication effort, we did no field experiments with replications or control treatments (see rationale in Thorne et al. 2019); all efforts were directed at swift elimination of conehead activity. Experiments should be done in areas where the species is permanently established rather than where an invasive population is possible to eradicate.

We recommend trying baits if circumstances prevent other approaches, or if a future bait is designed to target *Nasutitermes* or other Termitidae. Baits cannot be relied upon for swift, definitive colony suppression or elimination, but as with other approaches, they can be a useful ‘tool in the termite IPM tool chest’.

**Insecticides**

Before applying any insecticide, know your jurisdiction’s regulations and review the label to confirm that that use is allowed. Deviations must be approved by the authority that approves insecticide use in your state or area (in the United States, for example, the Environmental Protection Agency or state agency issuing an Experimental Use Permit or exemption).

Treatment data records logically include date, address, insecticide brand(s), active ingredient, formulation concentration, and total amount of insecticide(s) applied, infestation type (nest, tunnel or foraging center), size of each nest (or assign to a defined size classification tier/ranking), and treatment site location data (e.g., GPS coordinates). Observations or notes relevant to a particular nest or treatment situation are also recorded. These data will be useful to create maps, prepare reports of insecticide use, track infestation history and dynamics, and to plan areas and timing of future risk-based surveys.

Many insecticides are effective against conehead termites; reaching the insects is the hard part as discussed in the previous methodology sections. The FDACS eradication program used five
chemicals predominantly. Those active ingredients and the infestation situations in which they were used are listed in Table 3. Foams and other formulations, or techniques such as injecting insecticides into tree cavities, may be useful tools depending on specific infestation and regulatory situations.

**Containment: Preventing Spread by Stopping Dispersal Flights and Transport**

Most invasive species are difficult if not impossible to eradicate because containment is unachievable. Fish swim, rodents run, snakes slither, plant seeds carry in wind, and insects fly, highlighting examples of the practical challenges of constraining exotic plant, animal, or microbe movement. Aside from alate flight season, conehead termite colonies can expand their range only by walking (enabling them to move well over 100 m, but not kilometers) or by ‘hitchhiking’ to new locations via human transport. Thus if IPM interventions can halt or minimize the risk of natural and transport dispersal, the invasive population can be contained, controlled, and eradicated.

**Best Practices to Minimize Risk of Alate Dispersal**

Mature conehead termite colonies produce dark-winged dispersers (swarmers or alates) which—as far as is known—develop and fly annually with release over several weeks at the beginning of the rainy season. When colonies establish out of their native range, conehead termite life cycle may change such that alates mature and fly at other seasons, or at least develop during other months to become Queens and Kings in satellite nests radiating from an established nest. If the basic pattern persists that the vast majority of conehead alates mature seasonally (a life history characteristic of many termites and social insects), the advantage of intervening to minimize flight risk remains an efficient containment strategy.

The strongest, most decisive move in preventing dispersal flights is to physically destroy, then treat, conehead termite nests. As elaborated earlier, nests comprise the vital core of a mature conehead colony, housing the majority of developing brood including alates, and usually the Queens and Kings. Flight behavior begins by winged alates positioning on the nest or on vegetation near its surface. Crushing the nest carton and its inhabitants, then treating the removed nest’s ‘footprint’ and entry galleries into substrate wood or soil, decimates reproductive output and minimizes flight prospects.

Regardless of season, nest destruction and treatment are essential components of an invasive *Nasutitermes* eradication program. We recommend that conehead nests be removed, immediately crushed, and nest location treated with liquid insecticide whenever nests are found to prevent population growth. This intervention, adjusted to ESO if swift insecticide treatment cannot be teamed with nest destruction, is an urgent priority as flight season approaches.

Despite best efforts to treat invasive conehead nests prior to dispersal flights, there is potential for mature colonies to thrive undetected. Trapping alates is a logical approach to attempt to monitor density and location of swarmer witches during dispersal season. In practice, however, due to low population density in a young invasive infestation and relatively localized sticky or light traps, the probability of catching alates even if they fly is low. Implement alate monitoring if resources permit, but inspections, nest destruction, insecticide treatments, and outreach are far higher priorities. While we used Jackson traps (a simple, inexpensive trap featuring a covered, easily replaceable, disposable sticky board; ours had no pheromone or lure) any trap designed to catch flying insects can be placed within and surrounding currently known infested areas. Light attracts alates, so place traps near street, security, or solar lights. Traps can be hung on trees, fences, houses, or any fixture close to a light. Check traps at least every 2 wk; replace as needed. Conehead alates caught in the traps confirm that one or more mature colonies persists in the area. Even if conehead termite alates are not found during trapping, they may have flown but missed the traps, emphasizing the ambiguity of this tool in measuring progress of, or contributing to, a mitigation effort.

**Best Practices to Minimize Risk of Transport**

A critical aspect of the conehead containment program is preventing the termite from ‘hitchhiking’ via human transport, as occurred between Dania Beach and Pompano Beach, FL, locations over 20 km (13 mi) apart (Thorne et al. 2019). People living and working in infested areas must be aware of the invasive species, how to recognize and report signs of its activity, and how to support the eradication effort including preventing transport. All cellulose refuse moved out of the infested and surrounding locations must be treated before moving it off-site (best practice approach), or directed only toward responsible disposition (landfill or waste area where the discarded materials will be immediately, on the same day as arrival, incinerated or buried) (Table 1). Chipping plant material on site then leaving the chips within the infested zone, piled or spread, is also a responsible alternative (see Site Management subsection within IPM section). Moving live trees and shrubs for replanting, or transport of landscape timbers or wooden furniture out of the infested area to another property must be stopped. Young conehead termite colonies may hide within even small pieces of wood or cellulose such as corrugated cardboard boxes.

Entire conehead colonies, including mature Queens and Kings, can crawl out of a piece of wood or debris, walk up to 10 m (over 30 ft) or more, and relocate to a new nest site even during a single night. The risk of coneheads expanding their range can thus be substantially constrained by not moving wood or cellulose items out of currently infested and neighboring areas. If plant or structure debris must be moved, it must be responsibly disposed without sitting overnight in a truck bed or waste receiving area before incineration, fumigation, or burying (Thorne 2013, 2015; Thorne et al. 2019) (Table 1). Practically, responsible disposition of cellulose waste must be facilitated by the eradication team working with the community to solve the logistics of how and when potentially infested refuse will be picked up, and where it will be taken for swift, effective disposition without providing even a single night opportunity for hidden coneheads to relocate.

As another example of inadvertent transport of infested material establishing a conehead termite infestation in a new location, in spring 2015 our field team noticed that a pile of 16 railroad ties known to be infested with two large nests (Fig. 3h) were ‘missing’ several weeks after first discovery in Dania Beach, FL. Upon return to treat this recently located area of conehead activity, we found that the infested timbers were no longer on the site. Strong relationships with the local community fostered helpful support; the landowner informed our team that the railroad ties had been moved to a property 4.8 km (3 mi) west, in Davie, FL, to be used as landscape timbers.

We immediately contacted the recipient of the infested wood; he provided access to the property and assisted our efforts. Although the coneheads were on the Davie property for only a few weeks, they had moved from the railroad ties into trees, fencing, and stored...
wood debris on the property where the ties were placed. They built foraging tunnels to enter wood more than 21 m (70 ft) away, also infesting fruit trees, outdoor furniture, and a structure on a neighboring property. During our team’s first inspection a conehead Queen was found in a gallery 5 m from transported infested wood, showing that mature Queens can travel from their original nest. Compelled to take no further risks, all railroad ties were quickly fumigated then removed immediately (within hours of removing the fumigation tarps) so that no coneheads could reinfest the wood. The surrounding areas were treated and monitored carefully; no live coneheads were found on the Davie properties following that rapid response.

This case of conehead hitchhiking to a new location was foiled thanks to an observant field team, community information exchange, and swift actions, but it illustrates the ease with which infestations can spread by transport. This example also accentuates the importance of people who live and work on infested properties speaking openly about when and where wooden materials may have been transported during months preceding discovery of the invasive coneheads. Posting clear ‘Do Not Remove’ signs on infested materials, and involving property residents/owners in plans for treatment and timing to address infestations, are important steps to prevent inadvertent conehead termite transport.

Outreach: Engagement to Locate Active Coneheads and Minimize Spread

At first discovery of invasive conehead termites, people living and working on properties located within 0.4 km (0.25 mi) of infestations should be informed about the issue, why eradication is an important initiative, how to identify conehead foraging tunnels and nests, where to report possible sightings, and what to do before moving or disposing of infested materials. With this education, local residents and workers can help 1) map and track an infestation by watching for and reporting signs of conehead termites and 2) eliminate risk of moving conehead termites to new locations by understanding appropriate debris disposal practices. Even children readily learn how to recognize coneheads, and their outdoor adventures and sharp eyes may discover termites that adults missed.

In addition to personal contact meetings, a simple, effective strategy is to distribute illustrated brochures or doorhangers to each residence, business, or institution throughout survey areas and beyond (out at least 0.8 km (0.5 mi)). Media venues are also important to inform and periodically update residents, property owners, business owners and operators, agencies, landscapers, waste haulers and receivers, pest management professionals, agricultural producers, and natural resource managers. FDACS’ program had success with a comprehensive website, social media posts, and cultivating relationships with local public information officers. News and status reports about the program are influential, with a crucial vital benefit being to direct further queries to the eradication team.

Collaborations for Support and Assistance

A successful invasive conehead termite eradication program requires advocacy from senior invasive conehead leadership as well as partnering with stakeholders and informed professionals. Framing impacts in crisp, cost/benefit analyses of economic and environmental consequences offer the most compelling justifications for requesting support for an invasive conehead termite eradication effort. Funding the eradication program will pay off swiftly with high return on investment. If destructive coneheads become permanently established, damages to structures, agriculture, and natural areas—compounded by required insecticide treatments—will be expensive and enduring. Also emphasize that aggressive mitigation actions when a new conehead population is first discovered provide the best and least costly prospects for eradication. Point out that success in eliminating invasive conehead termites is achievable because, unlike most invasive termite species, 1) conehead colonies build conspicuous foraging tunnels and nests that are above ground, thus vigilant, repeated inspections can locate active conehead termite colonies, and 2) effective IPM methods for addressing this exotic pest are now proved, relatively inexpensive, and detailed in this paper as an eradication program guide.

Leadership in coordinating an invasive conehead termite eradication program involves fostering partnerships to expand expertise, financial support, and assistance in advancing containment and control. Stakeholders and experts, locally and across the broader region, have staff, skills, equipment, and/or communication resources that can substantially contribute to program success. For example, many required conehead-mitigation actions in infested areas, such as landscape management, waste disposal, communication with residents and media, and staff training programs, are already handled by local governments. Engaging municipalities to strategically adjust such activities to incorporate conehead termite awareness and IPM best practices is an efficient way for the eradication program, and stakeholders, to prosper from existing infrastructures and services. No matter what the department, agency, institution, business, or group engaged in the project, keeping their leader and key managers informed about significant developments, and strongly backing the conehead effort, will help propel support of and participation in the program.

Entities that may collaborate as Invasive Conehead Eradication Program partners include local, regional, and state (or province) governments; community groups; pest management and entomology professionals and associations; landscape and nursery experts and businesses; extension or equivalent education and outreach teams; regional and national agencies overseeing Agriculture, Environmental Protection, Forest Service, and Natural Resources. In-kind services (providing resources other than money, e.g., help, supplies or equipment) and volunteer participation are productive ways for collaborators to contribute. For FDACS’ south Florida program, we established the National Scientific Advisory Committee for the Conehead Termite Program, a group of seven broadly experienced termite research professors at universities across the United States. As needed, we also reached out internationally to Nasutitermes corniger experts. These colleagues helped steer FDACS’ science-based eradication program by offering their ideas and advice, reviewing protocols, highlighting potential funding sources and new technologies, and conveying updates about the program through their professional networks.

Conclusions

Conehead termites are adept invaders due to their abilities to ‘hitchhike’ within transported cellulose materials, then colonize and thrive in a wide variety of habitats where they can become destructive, expensive pests of agriculture, structures, and natural landscapes. However, because they build visible above ground foraging tunnels and nests, conehead termites can be found and targeted directly. IPM methods detailed in this paper, including site management, strategic insecticide treatments, and prevention of dispersal and transport are effective for containment, control, and ultimate eradication of...
invasive populations. The earlier and more aggressive those mitigation efforts, the least costly and most time efficient they will be, and the probability of successful eradication is greatest when control initiatives begin immediately upon discovery of a relatively small, young infestation.

Diligent inspections, and re-inspections, are essential to ultimately achieve conehead termite eradication. Once invasive species establish a breeding population, they are notorious for resurfacing and spreading. Conehead termites absolutely retain this risk. It is the nature of most eradication efforts that patient, meticulous monitoring must continue. Surprise discoveries of rekindled or uncharted infestations are often part of the systematic process toward elimination. The program must endure step by step perseverance toward complete eradication. Eliminating invasive populations of conehead termites (or any termite species with the genus *Nasutitermes*) will convey an immense return on investment by preventing this destructive, rapidly reproducing, highly adaptable species from establishing irreversibly and spreading to local and/or distant locations.

Acknowledgments

Sincere thanks to the Florida Department of Agriculture and Consumer Services' [FDACS'] senior leadership, including Commissioner Nicole 'Nikki' Fried, Deputy Commissioner Deborah Tannenbaum, Chief Science Officer Dr. Lisa Conti, as well as Division leaders Steve Dwinell, Kelly Friend, Greg Hodges, Andy Rackley, and Trevor Smith for supporting and advancing the invasive conehead termite eradication program. Kelly Friend, Greg Hodges, and two anonymous reviewers provided constructive comments on this manuscript. The following FDACS team members made outstanding contributions to the invasive conehead termite project: Sarah Bachat, Jessica Ber, John Bergquist, Amy Brown, Lisa Brown, Thom Coletti, Tyson Emery, James Long, Paul Mitola, Rusty Noah, Mike Page, Adriane Rogers, Shalom Siebert, Ellen Tannehill, Johanna Welch, and numerous careful inspectors who participated in annual surveys. We greatly appreciate excellent work by the following people and entities in progressing aspects of invasive conehead mitigation initiatives: Mike Beckers, Katia Bordy, Jeff Edwards, Joe Eger, Amy Roda, and Mike Wilson. We also thank Broward County Public Schools, School Board, and Water Management Division, and the Certified Pest Control Operators Association of Florida, Inc., Florida Pest Management Association, City of Dania Beach, and the National Pest Management Association. We are extraordinarily grateful to the National Scientific Advisory Committee for the Conehead Termite Program, Drs. Eldridge Adams, Brian Forschler, Susan Jones, Brad Kard, Faith Oi, and Pat Zungoli, for exemplary Committee for the Conehead Termite Program, Drs. Eldridge Adams, Brian Forschler, Susan Jones, Brad Kard, Faith Oi, and Pat Zungoli, for exemplary correspondence with their natural enemies in Puerto Rico. J. Agr. Univ. Puerto Rico 73: 69–60. Medina-Gaud, S., F. D. Bennett, A. E. Segarra-Carmona, and A. Pantoja. 1989. Notes on insect pests of soursop (Guanabana), *Annona muricata* L., and their natural enemies in Puerto Rico. J. Agr. Univ. Puerto Rico 29: 383–389. Mesenguer, M. T. and A. J. Mullins. 2005. New flight distance recorded for *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Flor. Entomol. 88: 99–100. Mill, A. E. 1992. Termites as agricultural pests in Amazônia, Brazil. Outlook Agric. 21: 41–46. Miura, T., Y. Rosin, T. Matsumoto. 2000. Molecular phylogeny and biogeography of the nasute termite genus *Nasutitermes* (Isoptera: Termitidae) in the pacific tropics. Mol. Phylogenetics Evol. 17: 1–10. Rosin, Y., and J. M. Pastels. 1986. Reproductive mechanisms in termites: polyclamy and polygyny in *Nasutitermes polygynus* (now synonymized with *N. corniger*) and *N. costalis* (now synonymized with *N. corniger*). Insectes Soc. 33: 149–167. Rust, M. K., D. A. Reiersen, E. O. Paine, D. Kellum, and K. Haagsma. 1998. Ravenous Formosan subterranean termites persist in California. Calif. Agric. 52: 34–37. Schufrahn, R. H., B. J. Cabrera, W. H. Kern, Jr, and N.-Y. Su. 2002. *Nasutitermes corniger* (= *Nasutitermes corniger*) (Isoptera: Termitidae) in Florida: First record of a non-endemic establishment by a higher termite. Flor. Entomol. 85: 273–275. Schufrahn, R. H., J. Kreek, A. L. Stalanski, and J. W. Austin. 2005a. Synonymy of Neotropical arboreal termites *Nasutitermes corniger* and *N. costalis* (Isoptera: Termitidae: Nasutitermitinae), with evidence from...
Scheffrahn, R. H., J. Krecek, A. L. Szalanski, J. W. Austin, and Y. Roisin. 2005b. Synonomy of two arboreal termites (Isoptera: Termitidae: Nasutitermitinae): *Nasutitermes corniger* from the Neotropics and *N. polygynus* from New Guinea. Flora Entomol. 88: 28–33.

Scheffrahn, R. H., J. Krecek, J. A. Chase, B. Maharajh, and J. R. Mangold. 2006. Taxonomy, biogeography, and notes on the termites (Isoptera: Kalotermitidae, Rhinotermitidae, Termitidae) of the Bahamas and Turks and Caicos Islands. Ann. Entomol. Soc. Am. 96: 463–486.

Scheffrahn, R. H., H. H. Hochmair, W. H. Kern, Jr, J. Warner, J. Krecek, B. Maharajh, B. J. Cabrera, and R. B. Hickman. 2014. Targeted elimination of the invasive termite, *Nasutitermes corniger* (Isoptera: Termitidae; Nasutitermitinae), from infested tracts in southeastern Florida. Internat. J. Pest Manag. 60: 9–21.

Snyder, T. E., and J. Zetek. 1924. Damage by termites in the Canal Zone, Panama, and how to prevent it. USDA Bull. 1232: 26.

Snyder, T. E., and J. Zetek. 1934. The termite fauna of the Canal Zone, Panama, and its economic significance, pp. 342–346. In C. A. Kofoid (ed.), Termites and termite control. Univ. Calif. Press, Berkeley, CA.

Thorne, B. L. 1982. Polygyny in termites: multiple primary queens in colonies of *Nasutitermes corniger* (Motschulsky) (Isoptera: Termitidae). Insectes Soc. 29: 102–107.

Thorne, B. L. 1983. Alate production and sex ratio in colonies of the Neotropical termite *Nasutitermes corniger* (Isoptera; Termitidae). Oecologia. 58: 103–109.

Thorne, B. L. 1984. Polygyny in the Neotropical termite *Nasutitermes corniger*: life history consequences of queen mutualism. Behav. Ecol. Sociobiol. 14: 117–136.

Thorne, B. L. 2013. Rebooting Florida’s effort to crush the invasive ‘Conehead Termite’. *Nasutitermes corniger*. Pest Perspectives (Flor. Pest Mgmt. Assoc.) March/April 2013. 8–13.

Thorne, B. L. 2015. Invasion of the coneheads! Pest Cont. Tech. 43: 36–50.

Thorne, B. L., and M. I. Haverty. 2000. Nest growth and survivorship in three species of Neotropical *Nasutitermes* (Isoptera: Termitidae). Environ. Entomol. 29: 256–264.

Thorne, B. L., M. S. Collins, and K. A. Bjorndal. 1996. Architecture and nutrient analysis of arbooreal carton nests of two Neotropical *Nasutitermes* species (Isoptera: Termitidae). Flor. Entomol. 79: 27–37.

Thorne, B. L., E. L. Vargo, E. S. Adams, and L. N. L. Johnson. 2019. Genetic analysis of invasive conehead termites, *Nasutitermes corniger* (Blattodea: Termitidae), reveals a single origin for two populations in Florida. J. Econ. Entomol. 112: 2545–2557.

Torales, G. J. 2002. Termites as structural pests in Argentina. Sociobiol. 40: 191–206.

Tucker, R. W. E. 1939. The termites of Barbados. Agric. J. Barbados 8: 132–139.

Webb, G. A., and C. McClintock. 2015. Elimination of the mound-building termite, *Nasutitermes exitiosus* (Isoptera: Termitidae) in South-Eastern Australia using bistrifluron bait. J. Econ. Entomol. 108: 2702–2710.

Wolcott, G. N. 1948. The insects of Puerto Rico. J. Agr. Univ. Puerto Rico. 32: 1–224.