IPM of Occasional Urban Invader Pest Species[1]

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Abstract Occasional invader species include a variety of arthropods such as amphipods, centipedes, insects, millipedes, pill and sowbugs, scorpions, and spiders as well as nonarthropod mollusks and worms. These species present unique challenges for development of effective IPM programs. Most occasional invaders are susceptible to desiccation and temperature extremes or are in a wandering or migration phase of their life cycle. Environmental factors such as weather and the condition of homes and home landscapes affect occasional invader infestations. Successful IPM programs have been developed for the garden millipede, *Oxidus gracilis* Koch, and the smokybrown cockroach, *Periplaneta fuliginosa* (Serville). Both programs rely primarily on habitat modification based on pest biology. Results indicate that these occasional invaders can be managed without resorting to broadcast application of nonspecific insecticides.

Key Words Water relations, temperature sensitivity, migration, avoidance, millipedes, peridomestic cockroaches, *Oxidus gracilis, Periplaneta fuliginosa*

Occasional invader species present unique challenges for development of effective IPM programs. Because these species are encountered infrequently, their biology and life cycles are poorly known. Even though infestations may, at times, become severe there is often a lack of suitable specimens for study and to establish laboratory colonies. Colonies are difficult to establish and maintain because there is little known about the environmental optima and food preferences of these species. Insufficient numbers of specimens prevent proper pesticide efficacy and behavioral preference studies. On a larger scale, there are usually few infested homes available to properly field test the components of IPM programs.

A number of arthropod groups including amphipods, centipedes, insects, millipedes, pill and sowbugs, scorpions, and spiders have been reported as occasional invaders of homes and other structures (Ebeling 1975, Bello 1997). Mollusks including snails and slugs and a range of worm-like organisms such as earthworms, horsehair worms, and land planarians also have been found in structures. Insects are generally the most common occasional invaders. A variety of beetles such as carabids and coccinellids frequently enter homes as do several caterpillar [fall webworm, *Hyphantria cunea* (Drury) and eastern tent, *Malacosoma americanum* (F.)] species, a number of peridomestic cockroaches [American, *Periplaneta americana* (L.), Austra-

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lian, *P. australasiae* (F.), Florida wood, *Eurycotis floridana* (Walker) and smokybrown, *P. fuliginosa* (Serville) cockroaches], and some springtails.

There are several common features of occasional invader species and their infestations. First, common aspects of pest biology include susceptibility to desiccation and temperature extremes, or that the pest is in a wandering or migration phase of its life cycle. Second, there are common features of the environment that lead to either massive increases in pest populations or that facilitate movement of pests into homes and other structures. Rapid changes in environmental temperature and humidity can stimulate pest movement while the biotic and abiotic conditions of new compared with aged structures and household landscapes may provide more hospitable areas for pest population growth and facilitate movement into structures.

Centipedes, millipedes, pillbugs, and sowbugs have few or no epicuticular lipids (Ebeling 1975) and, therefore, lack the waterproofing layer present in most insects. These groups generally desiccate rapidly and have relatively high cuticular permeabilities (>50 $\mu g\ cm^{-2}\ h^{-1}\ mmHg^{-1}$). Cuticular permeability values of representative occasional invader species, domiciliary pests, and corresponding nonpest species are presented in Table 1. Occasional invaders such as the garden millipede, *Oxidus gracilis* Koch, and smokybrown cockroach, have very high cuticular permeability values compared with the domesticated German cockroach, *Blattella germanica* (L.), and even subterranean termites. In addition to high cuticular permeability values, centipedes, millipedes, pillbugs, and sowbugs can not close their respiratory system with spiracle-like valves resulting in high rates of respiratory water loss. With high cuticular permeabilities and high rates of respiratory water loss, these groups in particular are quite susceptible to desiccation (Edney 1977).

Most occasional invader species that have been examined have relatively low (<45°C) critical thermal maxima (CTMax) and relatively high (>3°C) critical thermal minima (CTMin) compared with similar non-invader species. Critical thermal temperatures are determined by rapidly heating (CTMax) or cooling (CTMin) a specimen at a constant rate (e.g., 1°C/min) and saturated humidity and recording the temperature at which reversible knock down occurs (Appel et al. 1983, Appel 1991, Sponsler and Appel 1991). For example, the CTMax of the garden millipede is ≈38°C and mortality occurs above 40°C (Appel, unpub. data). In contrast, soldier and worker Formosan subterranean termites, *Coptotermes formosanus* Shiraki, that inhabit similar environments as the garden millipede have CTMax of >46°C (Sponsler and Appel 1991) and the southwestern drywood termites *Incisitermes fruticavus* Rust and *I. minor* (Hagen) have CTMax values of 52 and 51°C, respectively (Rust et al. 1979).

Many species that develop by complete metamorphosis do not pupate near their larval food source. For example, prior to pupation many last instar Diptera and Lepidoptera leave their larval food in search for appropriate pupation sites. Searching for pupation sites may lead larvae into poorly sealed structures where, because of their color, size, and movement, they become readily noticed by residents. For example, both fall webworm and eastern tent caterpillar larvae can become a nuisance when they leave their host plants and migrate across lawns and porches in search for pupation sites. These species can enter homes and "distribute themselves over the walls and ceilings" (Curran 1945). Calliphorid and sarcophagid maggots may be seen in structures following bat, bird, or rodent control particularly when the host died in a wall or ceiling void (Morse 1911, Griswold 1942, Davis 1953). Birds or mammals may also die in attics or crawl spaces and maggots could migrate down or up, respectively, into the living areas and may pupate in houseplant potting soil.

Table 1. Cuticular permeabilities and water composition of common occasional invader species and related domiciliary and nonpest species

Arthropod group	Family	Species	Occasional invader	Cuticular permeability (µg cm^{-1} h^{-1} $mmHg^{-1}$)	Water content (%)	Reference
Millipede	Paradoxosomatidae	*Oxidus gracilis* Koch	Yes	78.4 ± 2.59	60.6 ± 1.08	Appel (1988)
	Spirostreptidae	*Orthoporus ornatus* (Girard)	No	7.9 ± 1.79	36.6 ± 3.28	Crawford (1972)
Cockroach	Blattidae	*Periplaneta fuliginosa* (Serville)	Yes	130.0 ± 30.07	72.6 ± 2.70	Appel et al. (1986)
	Blattellidae	*Blattella germanica* (L.)	No	19.9 ± 0.80	65.3 ± 0.38	Appel et al. (1983)
	Blattellidae	*Blattella vaga* Hebard	No	26.3 ± 4.14	62.9 ± 0.93	Appel et al. (1983)
Termite*	Rhinotermitidae	*Coptotermes formosanus* Shiraki	No	37.5 ± 2.32 W 15.2 ± 0.93 S	70.0 ± 0.69 W 68.9 ± 0.27 S	Sponsler and Appel (1990)
	Rhinotermitidae	*Reticulitermes flavipes* Kollar	No	27.8 ± 1.37 W 31.5 ± 1.49 S	75.9 ± 0.36 W 73.3 ± 0.27 S	Sponsler and Appel (1990)

* For termites, S, soldier stage and W, worker stage.

Environmental factors, particularly rapid changes in weather (rain, freeze, etc.) can stimulate pest movement to avoid potentially lethal conditions. For example, millipede migrations may be stimulated by rainfall (Brade-Birks 1922, Koch 1985). Argentine ants, *Linepithema humile* Mayer, move indoors in response to freezing temperatures (Ebeling 1975). Rather than foraging for food, these ants usually forage for water that is unavailable outdoors. Structural and landscape environmental conditions also contribute to the movement of occasional pest species indoors. There are important differences between new and mature or aged structures and landscapes. Aged structures tend to have more points of entry including cracks, crevices, and missing or deteriorated screens than new or renovated structures. Mature landscapes tend to have larger and more dense ornamental plants, lawns with more moisture retaining thatch, and fruit trees that bear fruit. All of these conditions provide better shelter, moisture, and food than newly-planted landscapes. In addition, mature landscapes provide stable and complex ecosystems around the home. Informal observations and several in depth studies have related occasional invader infestations to the age of the environment (Appel 1988, Appel and Smith 2002, Appel, unpub. data). Massive garden millipede migrations in Alabama tend to be associated with 3 to 5-year-old housing developments built in previously forested areas. These migrations that lead to infestations usually occur in hot and humid summers that were preceded with early warm and wet springs. Smokybrown cockroach populations tend to be greater around older homes with large trees (Smith et al. 1995a).

Successful IPM Programs with Occasional Invader Species

Garden millipede. During June 1987, there was a major infestation of garden millipedes at a 2-year-old state mental health facility in Tarrant, AL. The facility consisted of 14 buildings sited in the shallow valley of a heavily-wooded forest (Appel 1988). An average of nearly 200 millipedes was entering each of the buildings every day. Residents were picking up millipedes from floors and eating them, and both residents and professional staff were slipping on crushed millipedes. Even though the millipedes were relatively harmless, their presence was a safety hazard and violated the state health code. Similar infestations of garden millipedes occur sporadically throughout the southeastern U.S. Hundreds to 1,000's of millipedes enter homes where they may stain carpets, drapes, and furniture. The millipedes are often handled by children and pets and emit an odorous defensive secretion that may startle or upset. The mere presence of garden millipedes in homes may cause annoyance, embarrassment, and sometimes fear.

Inspections for garden millipedes are relatively simple and consist of looking in dark and moist areas such as in heavily thatched grass, particularly where it contacts structures, under rocks, potted plants, ornamental timbers, and under all debris greater than about 10 cm in length. This is presence-absence sampling and is not particularly quantitative. However, the number of millipedes entering a particular area (e.g., a formal building entrance hall, or a garage) can be used to measure the relative effectiveness of a treatment.

Because insecticides are relatively ineffective against migrating garden millipedes, particularly at stopping migration into structures, an IPM system was developed based on the biology of the garden millipede. These millipedes are relatively sensitive to desiccation and have high cuticular permeabilities (Appel 1988). Desiccation results in a rapid decline in movement and eventually knockdown and death. Therefore, the goal of the IPM program was to make the environment and landscape surrounding the mental health facility as dry as possible. Environmental modifications included dethatching the lawns, closely mowing and edging the lawns (even lawns on the sloped valley areas), pruning, removal of all potential harborages such as large rocks, heavy mulch, boards, and other debris. The automatic watering system was adjusted to irrigate the lawns and landscape early in the morning rather than late in the afternoon. Adjusting the watering time results in less free water being available for the millipedes overnight and less water to saturate porous debris.

Without using any insecticides, the number of millipedes entering the mental health facility buildings declined ≈93% within 7 d. There was no change in the number of millipedes gaining entry in a nearby untreated control building. These results clearly indicate that an IPM program based on target pest biology can be safe and effective against migrating garden millipedes.

Smokybrown cockroach. The smokybrown cockroach is an important peridomestic pest throughout the southeastern U.S. and Southeast Asia (Appel and Smith 2002). Cockroaches are a source of potent allergens, may vector disease organisms, damage food, and are disgusting to most people. In infested neighborhoods, 100's of smokybrown cockroaches can typically be seen on decks, walls, and porches on warm summer evenings. Many of these cockroaches enter homes and other structures where they may become established. Smith et al. (1995a) developed a model that associated smokybrown cockroach infestations with house and landscape characteristics. Larger cockroach numbers were related to the age of the home and neighborhood as well as the presence of mature hardwood trees and many objects in the yard. This model was validated throughout Alabama (Smith et al. 1998) and is probably useful for the entire southeastern U.S.

Control of smokybrown cockroaches has been almost entirely based on the application of a band of insecticide around the perimeter of the home. A typical perimeter treatment consists of a 3-m-wide band around the house and the lower 1 m of the house exterior. However, this strategy allows high densities of cockroaches to develop outside of the relatively narrow treated perimeter (Piper and Frankie 1978). Unfortunately, most insecticides used for perimeter treatments degrade rapidly during the summer (when these cockroaches reach their maximal population density) in the Southeast because of the high daily temperatures (Harris 1975). For example, a chlorpyrifos wettable powder formulation applied to leaf litter and aged in a shaded outdoor environment, retained no activity against cockroaches after 12 d (Smith et al. 1997). Because of the relatively short life of residual insecticides, the ability of smokybrown cockroaches to move up to one city block in a night (Appel and Rust 1985), and the sensitivity of smokybrown cockroaches to desiccation, an IPM program was developed to reduce the use of broadcast insecticides and better manage infestations.

The IPM program was based on the house and landscape cockroach abundance model and included sanitation, environmental modification, and targeted application of insecticidal baits and sprays (Smith et al. 1995b). Much like the modifications used for garden millipede management, lawns were dethatched and closely edged and mowed, irrigation schedule modified, potential harborages such as large rocks, debris, and heavy mulch removed, and food sources such as pet food and feces and fallen fruit were also removed or reduced. To prevent entry into homes, all cracks and crevices were sealed with caulking, soffit and crawlspace vents were properly screened, and window screening was replaced and tightly fitted to windows.

Because environmental modifications alone could not rid a property of smokybrown cockroaches, faster-acting chemical treatments were also applied throughout each property. Chemical treatments included insecticidal gel and granular baits applied only near potential harborage areas (as predicted by the house and landscape model), spot sprays applied to points of entry, and total release aerosol foggers released in outbuildings (Smith et al. 1995b).

The IPM system reduced smokybrown cockroach abundance faster and longer (Fig. 1) than the conventional spray while using <80% of the active ingredient used in a typical perimeter treatment while spending the same amount of time applying the treatments (Smith et al. 1995b). In another study, even less active ingredient (95%) was used to get performance superior to that of conventional perimeter sprays (Smith et al. 1997).

Conclusions

Occasional invader species are typically sensitive to desiccation and temperature changes or extremes. Some species may be migrating or searching for pupation sites. Environmental factors including weather and the condition of a house and landscape may contribute to the growth of occasional invader populations and their entry into structures. IPM programs for occasional invader management should target the entire property, not just the areas immediately around a structure. IPM methods

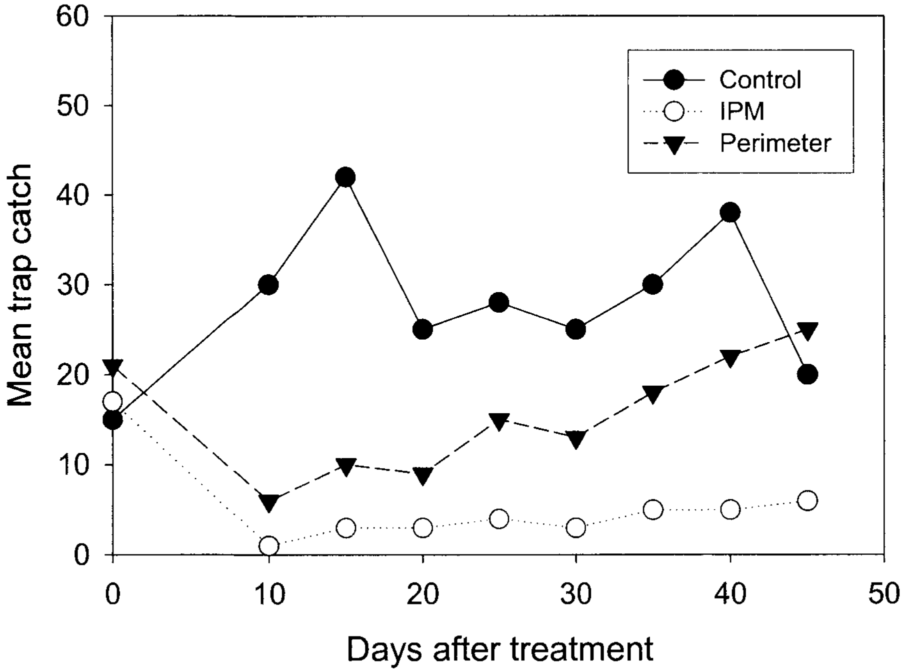

Fig. 1. Relative performance of an IPM program for management of smokybrown cockroaches compared with a conventional perimeter insecticide treatment and an untreated control (see Smith et al. 1995b).

for occasional invader species should include: exclusion through sealing the structure to prevent invasion, habitat modification to reduce the number of moist harborage areas, and targeted use of appropriate insecticides and insecticide formulations throughout a property.

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