SYMBIONTS OF INVASIVE INSECTS: CHARACTERIZATION, ECOLOGICAL ROLES, AND RELATION TO INVASIVE POTENTIAL AND MANAGEMENT STRATEGIES

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ABSTRACT

Most, and perhaps all, multicellular organisms house symbiotic microorganisms. Recent research identified a number of ways in which symbionts are critical to the success of various insects, yet we know very little about the symbiotic associations of the major invasive species. The information we do have is largely limited to two specific types of relationships, insect vectors of plant pathogens and entomopathogens. Yet these reflect only a subset of the most prevalent types of symbioses. This presentation makes four main points:

1. Invasive insects are really invasive species complexes.
2. Symbionts can enhance the invasive potential of introduced species.
3. Understanding insect-symbiont interactions can improve management.
4. Insect microbial communities provide useful models for testing general theories of biological invasions.

Few invasive tree-feeding insects have been evaluated for their major symbiotic associates. Among those species that have been considered, evaluations of gypsy moth (*Lymantria dispar* (L)) (Broderick et al. 2004), Subterranean Formosan termite (Adams and Boopathy 2005), Asian longhorned beetle (*Anoplophora glabripennis* (Motschulsky)) (Schloss et al. 2006), and emerald ash borer (*Agrilus planipennis* Fairmaire) (Vasanthakumar et al., in review) have revealed a high diversity of gut bacteria. Thus, these pests should not be viewed as single-species entities, but rather as species associations. The numbers of morphospecies and Operational Taxonomic Units vary among groups, and different symbionts show varying degrees of association with their hosts. These communities show structure, with different members dominating different life stages and sections of the gut. They are also responsive to the plant species on which the insect feeds. Many of these symbionts are culturable, but some can be detected only by using molecular methods.

These symbionts perform a number of functions that can benefit the insect, particularly in their abilities to exploit host plants (e.g., Dillon and Dillon 2004, Moran 2007). Some of these functions include: (1) Digestion, including cellulose metabolism, nutrient concentration, and nitrogen fixation; (2) Detoxification of plant defense compounds; (3) Pheromone production; (4) Protection from environmental extremes; (5) Defense against natural enemies. Almost all aspects of insect biology are facilitated by symbionts (Moran 2007). These functions relate to specific life histories of the herbivore. For example, we have observed celluloytic activity in cerambycids and buprestids but not in bark beetles. Likewise, we have observed use of symbiotic bacteria to inhibit gallery-invading fungi and thus protect brood in a number of bark beetle species (Cardoza et al. 2006).

An understanding of the identities, ecological functions, and community structures of symbionts can improve our ability to manage invasive species. These opportunities include improved treatments and improved monitoring and detection. For example, enteric gut bacteria play a crucial role in the toxicity of Bt to gypsy moth, as demonstrated by assays involving both Dipel and insecticidal crystal toxin administered through engineered *E. coli* (Broderick et al. 2006a). Similar results have been obtained with four other species of Lepidoptera, for a total of representatives from five families (Broderick et al. 2006b). Altering the gut microflora may provide opportunities for synergizing Bt activity. Likewise, some natural enemies of insect herbivores that feed below bark locate their cryptic prey

by cueing on volatiles produced by their microbial symbionts. This has been demonstrated, for example, with parasites of both the woodwasp *Sirex noctilio* F. (Madden 1968, Martines et al. 2006) and the bark beetles *Ips pini* Say and *Dendroctonus ponderosae* Hopkins (Adams and Six 2008, Boone et al. 2008). This can provide opportunities for discovering, synthesizing, and deploying attractants for both the pest and its natural enemies. In other cases, the boring insects themselves are attracted to volatiles produced by microorganisms with which they are commonly associated, through either direct or plant-mediated relationships. We are currently testing this approach for developing detection methods for emerald ash borer and its parasitoids.

Finally, insect microbial communities can provide useful models for testing general theories of biological invasions. Biological invasions are ultimately landscape-scale processes. As such, they do not lend themselves to controlled manipulations. Such manipulations would be both unethical and impossible to replicate. Because each insect contains a community, it provides an independent experimental unit. These units can be manipulated by administering antibiotics, introducing knockout phage, feeding various plant species and allelochemicals, exposing them to external factors such as temperature and crowding, and subjecting them to transplant experiments. They can be used to address some overarching questions such as:

1. What makes some species more likely to be invasive?
2. What makes some ecosystems more likely to be invaded?
3. What intervention tactics are most likely to succeed at various stages of invasion?
4. What are the roles of specific processes such as Allee effects, competitive displacement?

As with all models, insect symbiont communities have both practical and conceptual limitations, but they can be added to our overall toolbox of approaches.

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