CHAPTER 17. CONCLUSIONS

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While many areas of design for host range testing of carnivorous arthropods are still in flux, the following four points emerge in the mind of the senior editor as ones of particular importance for consideration in planning testing programs (points 1 and 2) or where important undecided theoretical issues exist (points 3 and 4).

Point 1: The species-rich, poorly known insect faunas of the world often make constructing representative test lists of native taxa extremely difficult.

Problem There are approximately 10 to 30-fold more species of insects than plants. While most non-tropical floras have nearly all of their species described, the same is not true of insects. Similarly, molecular phylogenies of plant groups are more common and more complete than for insects. These facts mean that if carnivorous insects are being introduced to continents, particularly ones with subtropical or tropical zones, there will be huge gaps in knowledge regarding native insects related to the target pest are that occur in the region. The smaller faunas of islands makes consideration of the impacts of biological control introductions on native insects of islands more tractable (see Causton, this volume, for an example in which impact of an introduction to the Galápagos was assessed relative to the islands' native insects). Comprehensive screening of the native species of a region is thus rarely possibly, even at the subfamily or tribe level. Rather, the fundamental host range needs to be determined by testing native species from the same genus as the target pest (if any exist), together with various species in native genera of the same tribe or subfamily as the pest. The lack of modern phylogenies for many insect groups, however, will make this task harder for insects than for plants as it may not be clear which genera (of perhaps dozens or more) are most closely related to genus of the pest.

A further complication is that, even for those species that have been described taxonomically, there may be little or no literature about their exact distributions, habi-

tats, host plants, biology, or habits. This may make it impossible to find them for use in host range tests (see Combs, this volume for an illustration of this point), or too difficult to rear them.

Potential solution Government support for taxonomic revisions and natural heritage studies of families with large numbers of pest species worldwide (and hence the groups most likely to furnish new invasive pests) are the means by to reduce this problem. Taxonomists, working with economic entomologists, could identify high priority taxonomic groups (and countries), which could then be studied in anticipation of future need.

Point 2: The inability to store test species with minimal maintenance (in contrast to the ease of storage provided by potted plants or seeds) forces testing programs for carnivorous arthropods to use field collected individuals (of the herbivorous test species) and to limit the test list severely to a few highly representative species.

(1) Use of field-collected individuals in laboratory tests.

Problem Field-collected individuals are used in laboratory tests because they are available and did not have to be reared (or were species that could not be reared). Basing a testing program around this approach (see Causton and also Fuester *et al.* in this volume) results in two problems. First, the list of species actually tested is at risk of being unbalanced as inclusion is based on opportunistic availability more than planning. Second, some test results may, later, have to be discarded (see Causton) because the test individuals turned out to have been previously parasitized or diseased.

Solution A better selection of test species may be possible if internet resources are used to link the researcher to large numbers of other entomologists who may have access to additional, desired species. The researcher could, for example, post lists of needed species, with alternative suggested species for each, to email lists or websites.

To reduce levels of contamination in field-collected species, organdy sleeves might be placed over colonies of desired species (at least for groups like aphids, scales, whiteflies, etc) to promote the development of colonies with lower rates of parasitism. Such partially protected field-reared insects could later be harvested as needed for tests. This approach would be less practical if such insects were only found in remote or difficult to rear locations.

(2) Picking highly representative species.

Problem Randomly selected members of a genus or tribe often must be used to represent their entire group. The validity of the assumption that "host suitability" is some quality that is broadly shared and gradually is diluted and lost with decreasing closeness to the target pest needs to be tested. An alternative model might be that suitability (for parasitoid oviposition, especially) changes abruptly among even closely related species.

Solution To determine if the assumptions on which this approach is based are warranted or not, a boot strap testing approach ought to be applied to several systems as

test cases. For a particular parasitoid, the native species nearest to the normal host could be identified and then four or five randomly selected groups (each a randomly selected list of test species) subjected to host range testing. If randomly selected species are representative of their taxonomic higher groupings, each group of randomly chosen species should yield similar estimates of the parasitoid's host range. If suitability varies less gradually, then more variation in predictions is expected from data among test groups.

Point 3: Unlike herbivores, which at least at times encounter several host plants in the same local area (in some cases side by side), parasitoids and predators are more likely to encounter potential hosts or prey one species at a time and thus live in a no-choice world.

Problem For herbivorous weed biocontrol agents, prior experience with the target weed and the opportunity to chose between the weed and a nontarget plant in the field is generally assumed. Because plants may at times (but clearly not always) grow in stands of mixed host species, this model does represent part of the world in which weed biocontrol agents search for hosts. Because of this, weed biocontrol scientists have shown a strong preference to use results from choice tests to estimate likely host ranges of herbivores being considered for introduction. However, even herbivores may not have such choices at all times: they might, for example, disperse into geographic regions where nontarget relatives of the target weed, but not the weed itself, are found.

For carnivorous arthropods searching for hosts or prey, resources are even more likely to be encountered one species at a time. Also, for parasitoids, it has been extensively shown that previous contact with the usual host decreases acceptance of other potential hosts (see Withers and Barton Browne, this volume). Both of these facts argue against using choice tests to predict risk to native test species from carnivorous arthropods proposed for introduction. Rather, it seems better to rely on no-choice tests.

Solution The best estimates of parasitoid host range seem likely to result from the testing of naïve, gravid females in a large test arena with moving air, in which each test species is presented separately and on the test herbivore's typical host plant. Negative results in such tests are validated by positive response of the same female parasitoid in an immediately following test in the same arena with the target pest on its typical host plant.

Point 4: The relative value of host taxonomy vs. the herbivore's host plant as a predictor of host range is likely to vary between groups of carnivorous arthropods.

Problem For parasitoids, successful host use requires both host location and host suitability. Factors determining the detectability of a host by a parasitoid include the presence of volatile compounds, sometimes from the host alone (e.g., its pheromones), but often from the herbivore's host plant (volatiles emitted when the plant is fed on by the herbivore). Suitability of a host for a parasitoid (at least for koinobiont species)

turns on the ability of the parasitoid's venoms, teratocytes, and symbionts to suppress the host's immune system. For idiobiont parasitoids (external parasitoids or parasitoids of stages like eggs that lack immune systems), suitability does not require suppression of an immune system, but rather will depend on the nutritional adequacy of the host's tissues.

These differences in biology are likely to strongly influence the relative value of two important potential predictors of a parasitoid's host range: (1) taxonomic relatedness of a test species to the normal host and (2) the similarity of the volatile blends emitted by the test species when feeding on its normal plant host to the volatile blend from the normal host when it feeds on its normal plant.

Solution For koinobiont parasitoids, how close a test species is taxonomically to the target pest is likely to be the best predictor of risk. So, test species should be selected by taking native species first from the same genus, then tribe, subfamily, etc., until the limits of the host range are discovered.

For idiobionts and predators, attraction to plants or restrictions to particular habitats might be a stronger factor shaping host ranges than is host taxonomy. Some parasitoids of leafminers, for example, attack hosts in several insect orders provided the leafminers are on the right sort of host tree (such as cherry) and have the right general mine shape and position (such as a blotch mine on the underside of the leaf). For such species, insects closely related to the target pest may not be hosts at all if they occur on differ types of plants or make differently shaped or positioned mines.

Continued debate on these and other points are needed to derive an effective system for predicting host ranges of carnivorous arthropods. The methods used for herbivorous arthropods, while instructive as a place to begin, do not provide an effective template. At the 2nd ISBCA meeting in Davos, Switzerland in September, 2005, discussion of these issues will continue.